TRANSMISSION OF POWER

WESTINGHOUSE ELECTRIC & MANUFACTURING CO.
PITTSBURGH, PA.

STADELMAN DEL. Tock Pub. Engr. Co. Pitts. Pa.

TRANSMISSION OF POWER.

DESCRIPTION OF

SYSTEMS AND APPARATUS

FURNISHED BY

WESTINGHOUSE

ELECTRIC AND MANUFACTURING COMPANY

PITTSBURG, PA.

PREPARED BY

L. B. STILLWELL, ELECTRICAL ENGINEER,

PITTSBURG, PA.
FORT PITT ENGRAVING CO.,
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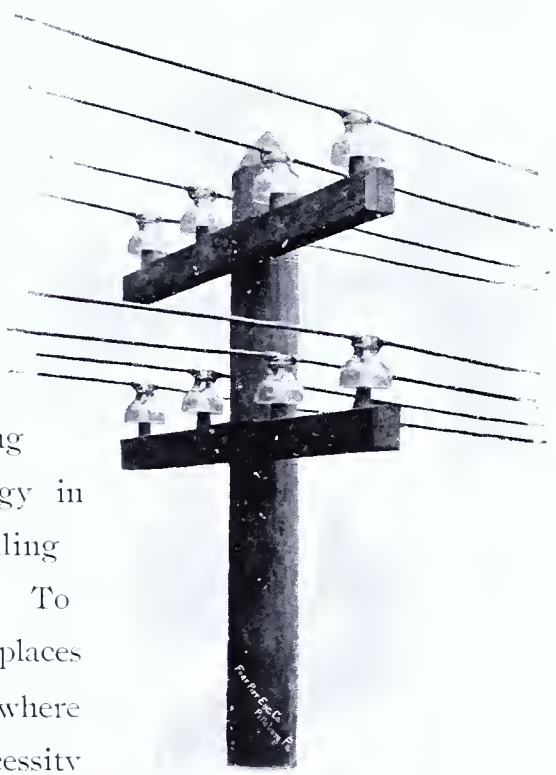
Electric Transmission of Power.

ALL INDUSTRIAL operations involve the utilization of energy. Whenever work is to be done energy must be expended. We find in Nature two principal stores of energy of which we may avail ourselves, namely:—coal and falling water. In coal we find the energy in its stored or potential form; in falling water in its live or kinetic form. To convey this energy from those places where Nature provides it to points where it may be utilized is to meet a necessity of civilization, and to effect its conveyance efficiently, is, perhaps, the most important work of modern engineering.



The economic problem is to bring together at minimum cost the energy to be utilized and the work to be done. Where the energy is derived from coal this is usually accomplished by hauling the coal from the mine to the place where power is required, and there burning it under boilers. Another means of attaining the same end is to locate engines at the

mine, and transmit the energy in its kinetic or live form by means of electric apparatus, cables, or such other methods as may be applicable to the existing conditions.

Where water power is the source of energy, transmission is usually effected in the kinetic or live form. The principal methods available are :—

Hydraulic transmission.

Pneumatic transmission.

Rope transmission.

Electric transmission.

Which of these methods should be adopted for any given case, will depend upon prevailing conditions and requirements. Except for very short distances, however, electric transmission has no rival in point of economy, flexibility, efficiency, or general utility.

Intimately associated with the problems of transmission are the problems of distribution of power. The cost of developing an aggregate of 1,000 h. p. by a hundred small steam plants far exceeds the cost of developing the same amount of power by a single engine, and, under ordinary conditions, the difference will be more than sufficient to pay a large interest upon the necessary investment in generators, distributing circuits, and motors required to distribute this power from a single generating station. In these cases the saving of fuel is only a part of the argument in favor of distribution from a central station. The saving in supervision, attendance, etc., and the great economy of space effected by the substitution of a motor for a small steam plant are often of even greater importance than the resulting economy of coal.

Distance and Electromotive Force.

THE DISTANCE over which power can be transmitted electrically depends primarily upon the electromotive force which may be safely and judiciously employed. One of the factors entering into the cost, and, consequently, into the annual charges of an electric plant, is the investment in conductors between generator and motor. This cost increases, — other things being equal,—with the distance, and it increases, not in direct proportion to the distance, but in proportion to the square of the distance. In other words, with a given electromotive force, the transmission, at a certain efficiency, of a fixed amount of energy requires four times as much copper if the distance be two miles as is necessary if the distance be one mile. On the other hand, the amount of copper varies inversely with the square of the electromotive force employed; that is to say, if the distance and other conditions except the electromotive force be fixed, it will require one-fourth as much copper to transmit a certain amount of energy if 2,000 volts be used as will be required to transmit the same energy with equal efficiency over the same distance if 1,000-volts be employed; and it will require one-hundredth as much copper if 10,000 volts be used as will be necessary if the potential be limited to 1,000 volts.

The great economy in conductors resulting from the use of high potentials will be understood upon examination of the following Chart and Table:

Chart 1.

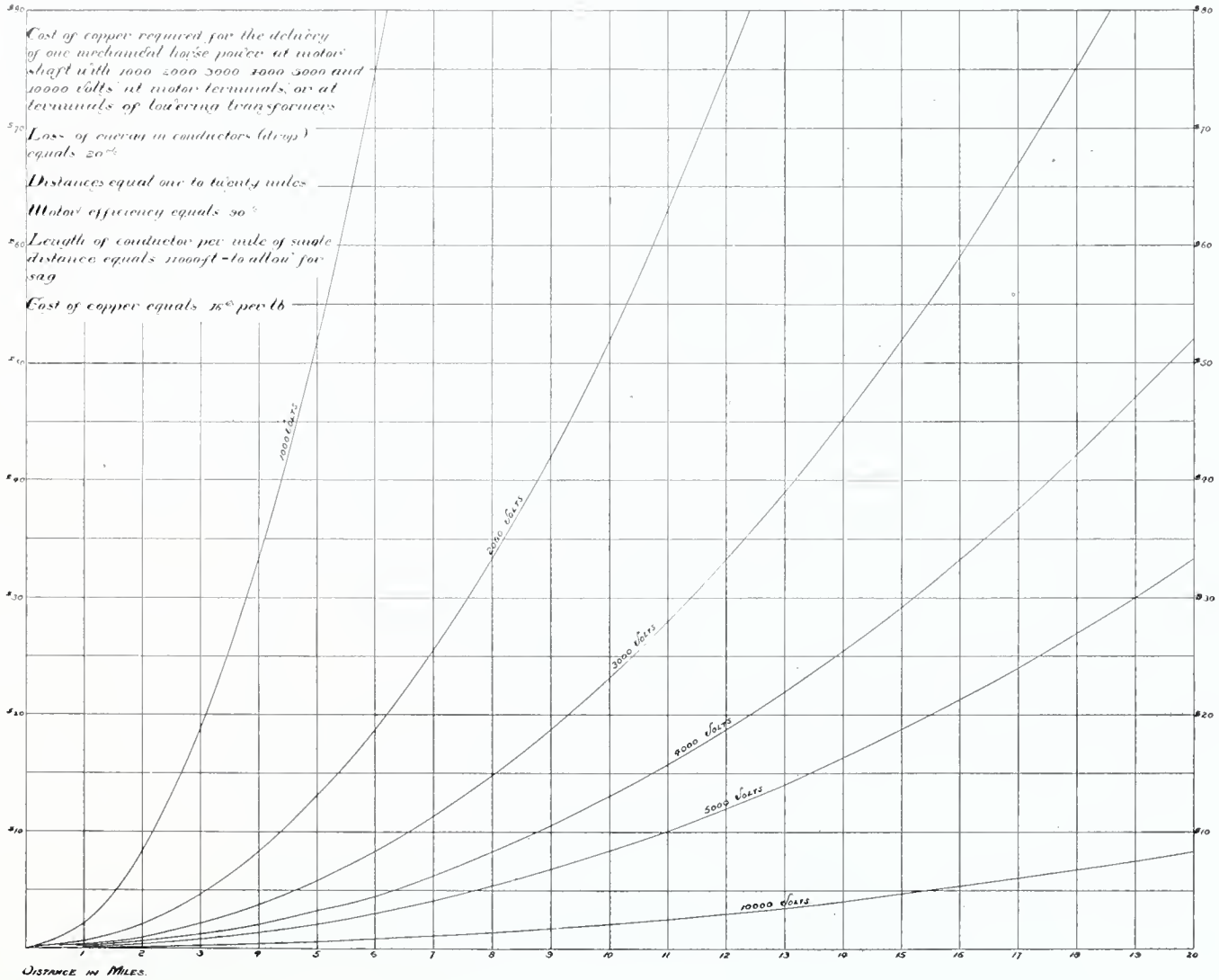

Cost of copper required for the delivery of one mechanical horse power at motor shaft with 1000 2000 3000 4000 5000 and 10000 volts at motor terminals, or at terminals of lowering transformers
Loss of energy in conductors (drop) equals 20%
Distances equal one to twenty miles
Motor efficiency equals 90%
Length of conductor per mile of single distance equals 1000ft - to allow for sag
Cost of copper equals 16¢ per lb
1000 volts
2000 volts
3000 volts
4000 volts
5000 volts
10000 volts
$80
$70
$60
$50
$40
$30
$20
$10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance in Miles.

TABLE 1.

Cost of copper required for the delivery of one mechanical horse power at motor shaft with 1,000, 2,000, 3,000, 4,000, 5,000 and 10,000 volts at motor terminals, or at terminals of lowering transformers.

Loss of energy in conductors (drop), equals 20 per cent.

Distances equal one to twenty miles.

Motor efficiency equals 90 per cent.

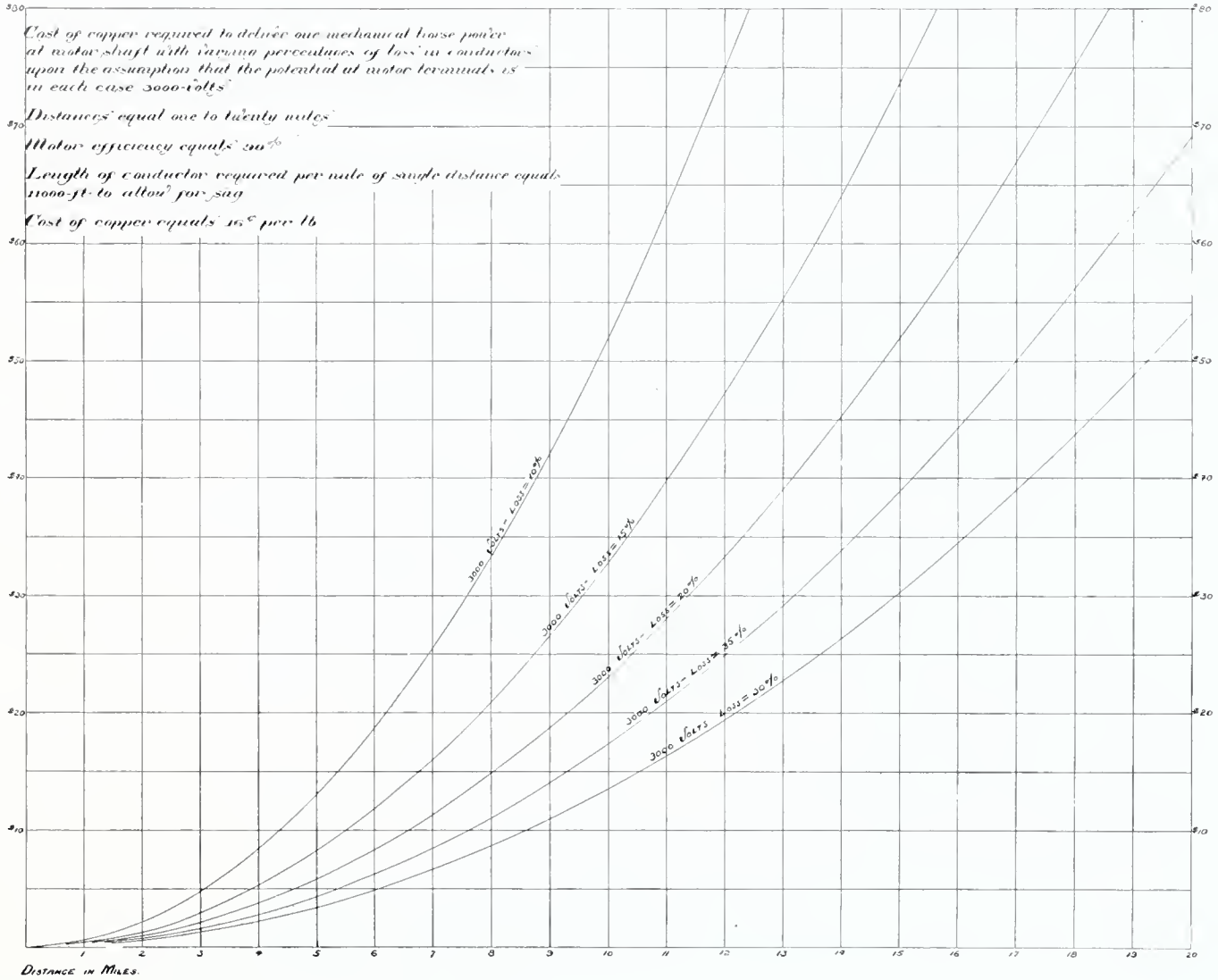
Length of conductor per mile of single distance equals 11,000 feet, to allow for sag.

Cost of copper equals 16 cents per pound.

Miles.	1,000 v.	2,000 v.	3,000 v.	4,000 v.	5,000 v.	10,000 v.
1	$ 2.08	$ 0.52	$ 0.23	$ 0.13	$ 0.08	$0.02
2	8.33	2.08	0.93	0.52	0.33	0.08
3	18.70	4.68	2.08	1.17	0.75	0.19
4	33.30	8.32	3.70	2.08	1.33	0.33
5	52.05	13.00	5.78	3.25	2.08	0.52
6	74.90	18.70	8.32	4.68	3.00	0.75
7	102.00	25.50	11.30	6.37	4.08	1.02
8	133.25	33.30	14.80	8.32	5.33	1.33
9	168.60	42.20	18.70	10.50	6.74	1.69
10	208.19	52.05	23.14	13.01	8.33	2.08
11	251.90	63.00	28.00	15.75	10.08	2.52
12	299.80	75.00	33.30	18.70	12.00	3.00
13	352.00	88.00	39.00	22.00	14.08	3.52
14	408.00	102.00	45.30	25.50	16.32	4.08
15	468.00	117.00	52.00	29.25	18.72	4.68
16	533.00	133.00	59.00	33.30	21.32	5.33
17	600.00	150.00	67.00	37.60	24.00	6.00
18	675.00	169.00	75.00	42.20	27.00	6.75
19	750.00	188.00	83.50	47.00	30.00	7.50
20	833.00	208.00	92.60	52.00	33.32	8.33

The figures given in Table 1 are illustrated graphically in Chart 1, the abscissæ representing distances in miles from generator to motor, and the ordinates cost in dollars per horse power delivered at motor shaft.

Chart 2.


Cost of copper required to deliver one mechanical horse power at motor shaft with various percentages of loss in conductors upon the assumption that the potential at motor terminals is in each case 3000-volts
Distances equal one to twenty miles
Motor efficiency equals 90%
Length of conductor required per mile of single distance equals 11000-ft. to allow for sag
Cost of copper equals 16¢ per lb
3000 Volts - Loss = 10%
3000 Volts - Loss = 15%
3000 Volts - Loss = 20%
3000 Volts - Loss = 25%
3000 Volts - Loss = 30%
$80
$70
$60
$50
$40
$30
$20
$10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Distance in Miles.

The cost of conductors depends not only upon the electromotive force employed, but also upon the loss of energy allowed in the circuits.

TABLE 2.

Cost of copper required to deliver one mechanical horse power at motor shaft with varying percentages of loss in conductors, upon the assumption that the potential at motor terminals is in each case 3,000 volts.

Distances equal one to twenty miles.

Motor efficiency equals 90 per cent.

Length of conductor required per mile of single distance equals 11,000 feet, to allow for sag.

Cost of copper equals 16 cents per pound.

Miles.	10 per ct.	15 per ct.	20 per ct.	25 per ct.	30 per ct.
1	$ 0.52	$ 0.33	$ 0.23	$ 0.17	$ 0.13
2	2.08	1.31	0.93	0.69	0.54
3	4.68	2.95	2.08	1.55	1.21
4	8.32	5.25	3.70	2.77	2.15
5	13.00	8.20	5.78	4.33	3.37
6	18.75	11.75	8.32	6.23	4.85
7	25.50	16.00	11.30	8.45	6.60
8	33.30	21.00	14.80	11.00	8.60
9	42.20	26.60	18.75	14.00	10.90
10	52.06	32.78	23.14	17.31	13.50
11	63.00	39.75	28.00	21.00	16.30
12	75.00	47.20	33.30	24.90	19.40
13	88.00	55.30	39.00	29.20	22.80
14	102.00	64.20	45.30	33.90	26.40
15	117.00	73.75	52.00	38.90	30.30
16	133.00	83.80	59.00	44.30	34.50
17	150.00	94.75	67.00	50.00	39.00
18	169.00	106.00	75.00	56.20	43.80
19	188.00	118.00	83.50	62.50	48.70
20	208.00	131.00	92.60	69.25	54.00

Table 2 is illustrated graphically in Chart 2, in which, as in Chart 1, abscissæ represent distances in miles from generator to motor, and the ordinates cost of conductors in dollars per horse power delivered at motor shaft.

The foregoing curves and tables illustrate the necessity for the use of high potentials in transmitting power over considerable distances. For example, from Table 1 we find that to deliver one mechanical horse power at the pulley of a motor located at a point five miles from the generator, allowing a loss of twenty per cent. in the transmission circuit, it is necessary to invest about $50 in copper conductors if the potential at the motor is limited to 1,000 volts. To deliver the same amount of power at the same percentage of loss at a distance of ten miles will, if the same potential be employed, necessitate an investment of $200 in copper.

Transmission over great distances may be accomplished by the use of very high potentials, and for any given distance the investment in copper conductors decreases rapidly with increase of potential; but it must be remembered that the difficulties encountered in proper construction and insulation of the circuits will increase as the potential is raised. A plant should be so installed as to practically obviate all danger of interruption of service; and, therefore, the potential selected in any given case, while high enough to secure reasonable economy as regards investment in conductors, should not be so high as to involve any undue risk of reliability of operation.

Insulation of Apparatus for High Potentials.

WITHIN certain limits, as before explained, the employment of high potential means economy in investment, and, therefore, one of the problems which has presented itself to inventors and designers of electrical apparatus has been to devise means whereby high potentials may be safely employed and controlled. During the past ten, or, perhaps, fifteen years, a vast amount of work has been done in this direction, but until recently the results obtained were largely negative. This was due to the fact that for a long time the attention of those working in this field was particularly and almost exclusively limited to one of the two great classes of electric machinery, namely: direct or continuous current apparatus. More recently, however, the possibilities of alternating current machinery have been investigated and developed, and its peculiar and commanding advantages are now generally recognised.

The superiority of alternating current apparatus for transmission rests chiefly upon two characteristics, viz.:

FIRST:—the comparative simplicity of construction of alternating current generators and motors.

SECOND:—the possibility of employing transformers.

Experiments, and, indeed, a wide and general experience, have pretty thoroughly demonstrated the limitations of potential in electrical machinery operating with direct or continuous currents. Improvements in construction and in methods of insulation have

done much to increase safety, and to make possible the use of higher potentials than were practicable a few years since; but investigation and experience have alike brought out the fact that there are certain limitations due to the characteristics of the continuous current system, and certain fundamental peculiarities in the construction of direct current machinery, which effectually prevent the employment of any very high potentials.

That part of a direct current machine which is especially liable to cause trouble when high potentials are employed is the commutator, which is, of all the essential elements of a generator or motor, the most complicated and expensive, while it is, at the same time, the most delicate and most liable to damage. The employment of this device also imposes difficulties as regards the insulation of the conductors used in winding the armature, since it is necessary that every turn, or each group consisting of a small number of turns, be connected to a segment of the commutator. This necessitates breaking the winding into many parts, and leaving a great many exposed conductors, which, of course, make thorough insulation of the armature very difficult.

In an alternating current machine there is no commutator, and, at the same time, the manner of placing the wires on the armature admits of better protection, more thorough insulation, and greater facility of repair, since one wire is wound continuously, and there is no exposed part except the collector rings, to which the ends of the wires are connected. It is, therefore, possible to insulate the armature of an alternating current machine to withstand a much higher potential than may be safely applied to the armature of a direct current generator or motor.

An alternating current collector consists simply of continuous rings of hardened copper mounted upon the shaft which carries the armature, and separated from each other and from the shaft by heavy rings of insulating material. There are very few parts, and this fact, of course, facilitates high class mechanical construction.

A Two-Ring Collector, built for a very large machine, is shown in the accompanying photograph. Two-ring collectors of this type are employed in the two-wire synchronous system, while four-ring collectors are generally employed in the Tesla polyphase system.

The simplicity of construction, and the ease with which the rings of the collector may be insulated for very high potentials,

are evident at a glance. There is no sparking whatever between the brushes and collector of an alternating current machine, and the mechanical friction of the brushes upon the continuous ring is, of course, a minimum. A collector that is properly used will last almost indefinitely.

The illustration shows the commutator of a large direct current generator of the type most suitable for power purposes. It consists of a large number of copper segments mounted upon the periphery of a cylinder. In the completed machine the commutator is mounted upon the armature shaft, and each segment is connected to the conductor with which the armature

is wound. Segments are separated from each other and from the cylinder upon which they are mounted by strips and bushings of insulating material. In our machines mica insulation is employed; segments are of tempered copper; and the design and workmanship are of the best. Carbon brushes are used, and friction is reduced as far as possible.

Transformers.

WE HAVE already said, the second great advantage of the Alternating Current System over the Direct Current System as regards transmission of power, is found in the use of raising and lowering transformers for increasing and reducing potential. Alternating current transformers have no moving parts, and in their construction special means of insulation, impracticable in machinery comprising a rotating element, may be adopted. There is no electrical connection between primary and secondary coils, and, by immersing these in oil, an extremely effective insulation can be secured. The photograph upon the opposite page illustrates the construction of such a transformer of ten kilowatts capacity adapted to 10,000-volt service. The transformer proper,—consisting of the primary and secondary coils and the laminated iron surrounding them,—is shown removed from the box or case which contains it when in use. The case is provided with special insulated terminals, with an oil gauge, and with a stop-cock, to be used in drawing off the oil, if, for any reason, that is necessary. Some of the plates of laminated steel used in building up the transformer are also shown.

Where raising transformers are used it is unnecessary to employ high potential at the generator, which is, therefore, usually wound to deliver its current to the primary terminals

of the raising transformers at a comparatively low voltage. The transformed energy is delivered from the secondary terminals of the transformers to the transmission circuit at a very high potential,—say 5,000 or 10,000 volts. At the distant end of the line where the power is to be used, step-down transformers of similar construction reduce the potential to a point at which

it may be safely distributed to the motors. The high potential used in transmission is in this manner limited to the raising and reducing transformers and the transmission circuit, while the motors, switches, and all measuring and indicating instruments are exposed only to potentials against which it is easy to provide perfectly effective insulation.

DIAGRAM 1.

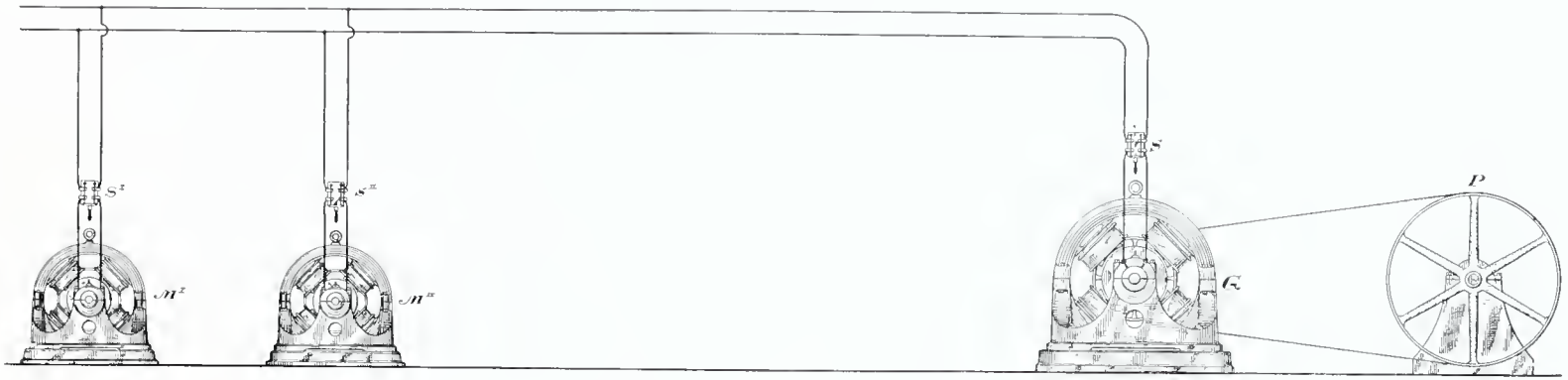
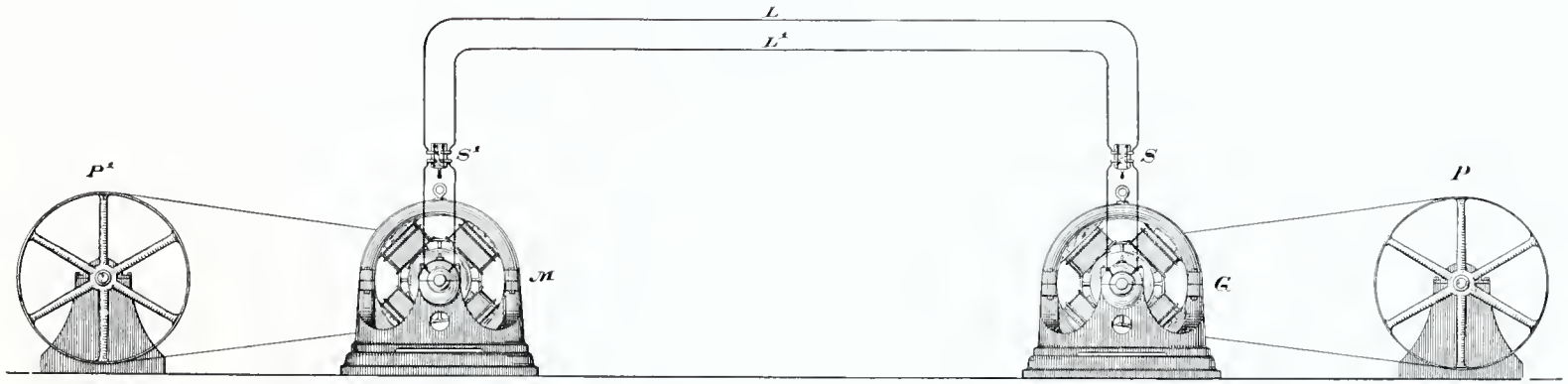


DIAGRAM 2.



Direct Current Systems.

WHILE LIMITATIONS as to the potential which may be safely used in connection with direct current generators and motors restrict the application of this type of apparatus to those cases in which power is to be transmitted over a very moderate distance only, direct current machinery is, nevertheless, admirably adapted to transmission and distribution of power where distances are not excessive, and where a great variety of conditions as regards motor service are encountered. Distribution is most easily effected by means of a constant potential system, since to such a system, motors of all sizes, performing many different kinds of work, may be connected without mutual interference.

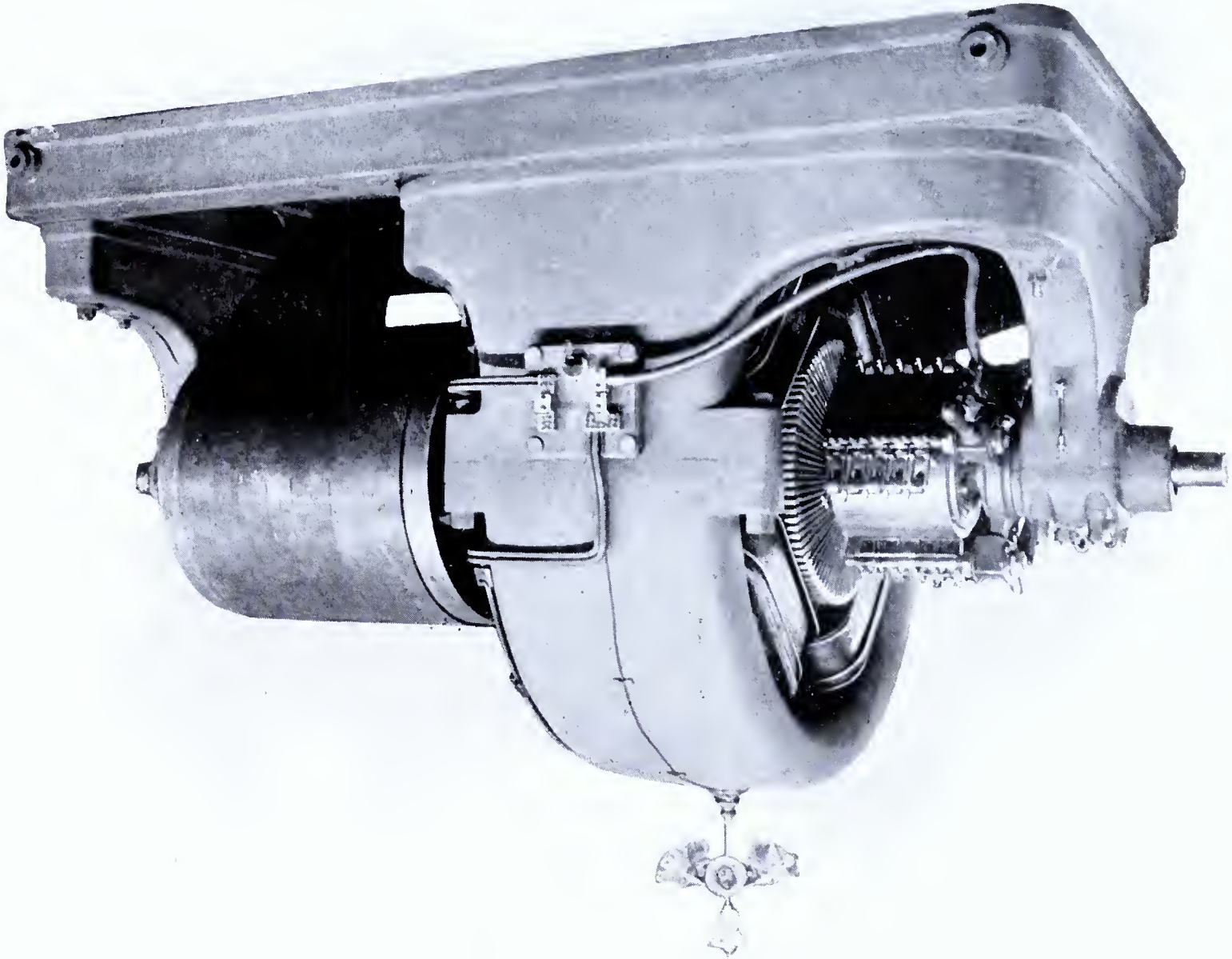
Transmission under conditions which make it possible to employ a motor for each generator can be effected by a series system; that is to say, a system in which both generator and motor have their fields in series with their armatures. The application of this system is, however, very limited; and, while it is possible to employ higher potentials than can be safely used in constant potential direct current apparatus, its usefulness is comparatively restricted.

Referring to Diagram 1, the pulley, P, represents the source of power employed to drive the generator, G. The switch, S, is used to connect the generator, G, and the circuit. The motors, M′, M″, are respectively connected to the circuit through the switches S′, S″. If the generator, G, supplies to the circuits an approximately constant potential, either of the motors,

M′, M″, may be connected with or disconnected from the circuit without interference. For example, the motor, M′, will run at a certain predetermined speed, and will do its work equally as well when M″ also is receiving current from the circuit as when M″ is not in operation, assuming, of course, that the machines are properly designed, and that the loss in the circuit is not excessive.

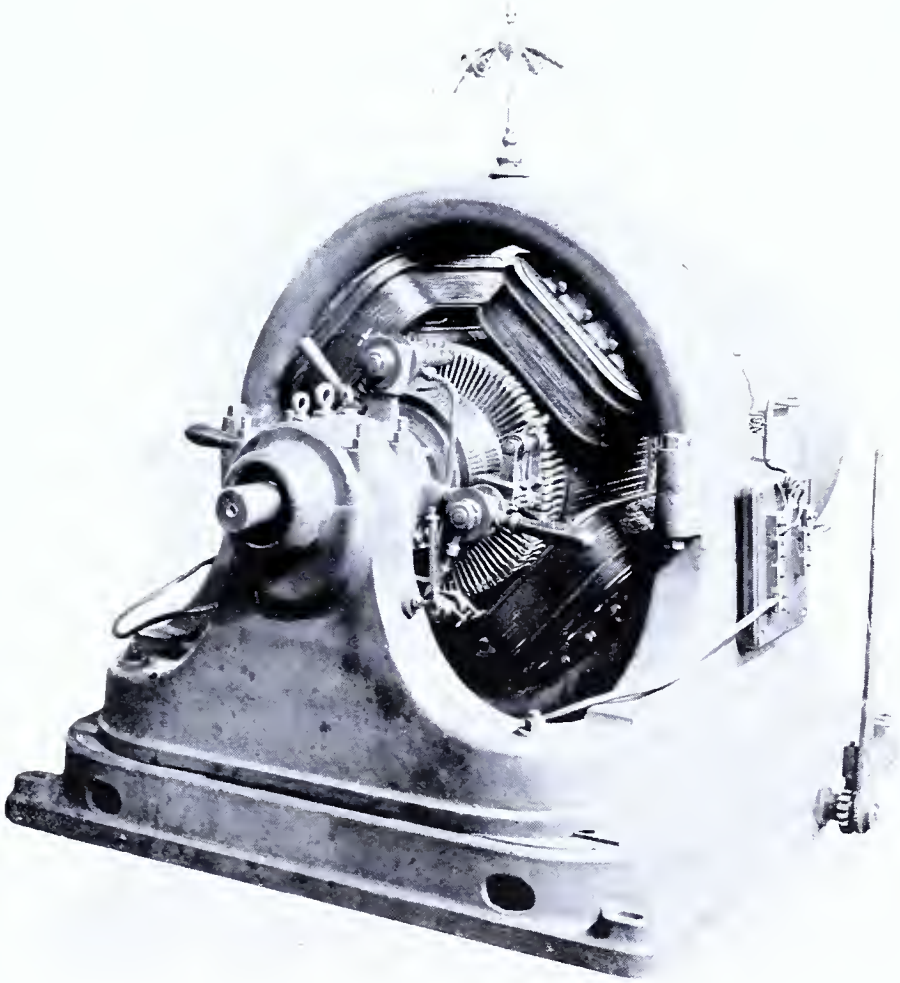
In Diagram 2, the pulley, P, represents the source of power employed to drive the generator, G. The switch, S, is used to connect the generator with the circuit, L,L′. The current from the circuit is delivered to the motor, M, through the switch, S′. The motor supplies power to the pulley, P′, through a belt.

We build a number of types of direct current machinery, and of each type machines of many different sizes and capacities are made. The photograph on the opposite page illustrates our 400 h.p. Multipolar Generator, which is very extensively used in supplying current to street railway systems. This machine,—and others of our line of multipolar generators,—is believed to embody every substantial excellence known to the art of dynamo design. The beauty of the design and modeling are well shown in the photograph. The machine is provided, in addition to the bearings required by the armature, with an outboard bearing outside the pulley, whereby undue and unequal strain of the shaft is prevented. All bearings are of the improved self-oiling type, and are exceptionally large. Oil gauges are provided, indicating the height of the oil in the reservoirs under the bearings. The oil cannot escape, and may be used over and over again. All dust is excluded from the reservoir. Carbon brushes are employed, and the brush capacity of the machine is ample.



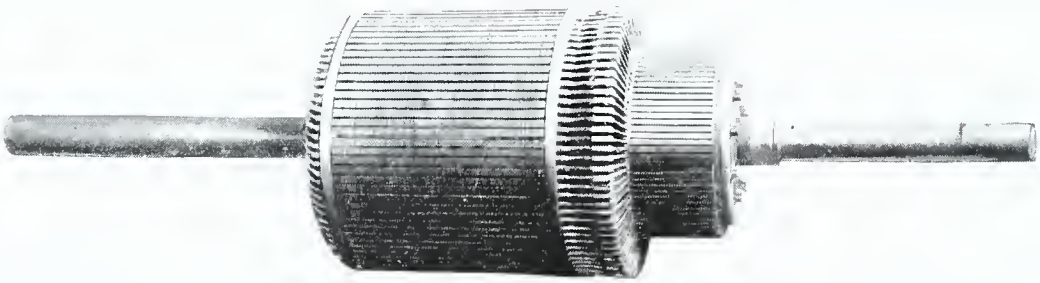
A feature of the utmost value, and one that is peculiar to our multipolar machines, is the employment of laminated steel field poles, which are cast into the yoke or frame of the machine. Each pole piece is built up of a large number of extremely thin sheets of soft steel, manufactured expressly for our Company, and conforming to a predetermined formula, which experience has shown gives the best results as regards magnetic permeability. As a result of this construction the magnetic field is extremely powerful,—nearly double what is possible where cast iron is employed. The advantages of this in the design and operation of the generators are manifold, but perhaps the most important lies in the fact that the reaction of the armature is practically powerless to disturb the lead, and, consequently, the machine may be operated under any load within the limit of its capacity, and even under a load considerably exceeding its normal capacity, without shifting the brushes, and without spark at the commutator. The great practical value of this characteristic will be understood by all who are familiar with the operation of direct current machinery.

On page 29 we illustrate our 100 h.p. Multipolar Generator. This machine,—with slight changes in the connections of the field winding,—may be used as a constant speed motor, as may also any of the machines of this line from the smallest to the largest. As generators they are compound wound, and when driven at constant speed will deliver current at a potential which increases gradually from 500 to about 550 volts, this increase corresponding with variations in the amount of current which they are called upon to supply. The object of this over-compounding is, of course, to compensate for the loss in the circuits, the intention being to deliver to motors a constant potential of 500 volts.



100 H. P. Multipolar Generator.

An Armature of the type used in these multipolar generators is shown below. In this, as in the field, workmanship and material are the best obtainable, while the method of construction is such as to entirely obviate the use of band wires to hold the conductors in place. The armature core is composed of many hundreds of thin steel plates similar in quality to those used in the field poles. The conductors are threaded through slots near



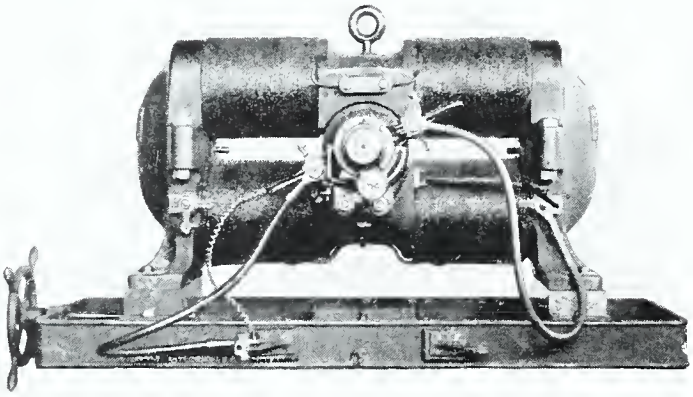
the periphery of the core, and are effectually insulated from the iron by heavy insulating tubes. The greatest care is taken in the construction of the commutator. Hardened copper is employed, and each segment is separated from the adjacent segments by the best mica insulation.

Our standard line of multipolar generators comprises the following:—

MULTIPOLAR DIRECT CURRENT BELT-DRIVEN GENERATORS.

MACHINE.	CAPACITY.	OUTFIT.		WEIGHT IN POUNDS.			SPEED.	PULLEY.	
500-Volt D. C. Generator.	Horse Power.	Amperes.	Volts	Net.	Largest Piece Gross.	Gross Boxed for shipm't.	Speed R. P. M.	Diameter.	Face.
No.								Ins.	Ins.
00	80	120	500	8809	3393	10010	750	26	10
0	100	150	500	12000	4500	13250	750	26	14
1	150	225	500	16500	4900	18000	625	30	16
2	250	375	500	21150	9980	23150	535	34	28
3	300	450	500	35000	10030	37800	500	37	32
4	400	600	500	38000	11270	41000	465	40	40
5	500	750	500	64800	12900	68500	375	48	48
6	700	1050	500	70100	14859	74100	390	60	56

In addition to the multipolar generators we manufacture several other direct current types. The illustration on page 32 is a photograph of a generator of our Horizontal Consequent Pole Type, which is extensively used where machines of moderate size,—ranging from 20 h.p. to 80 h.p.,—are required. They are specially noteworthy on account of their very moderate speed. The same machines may be used as motors.



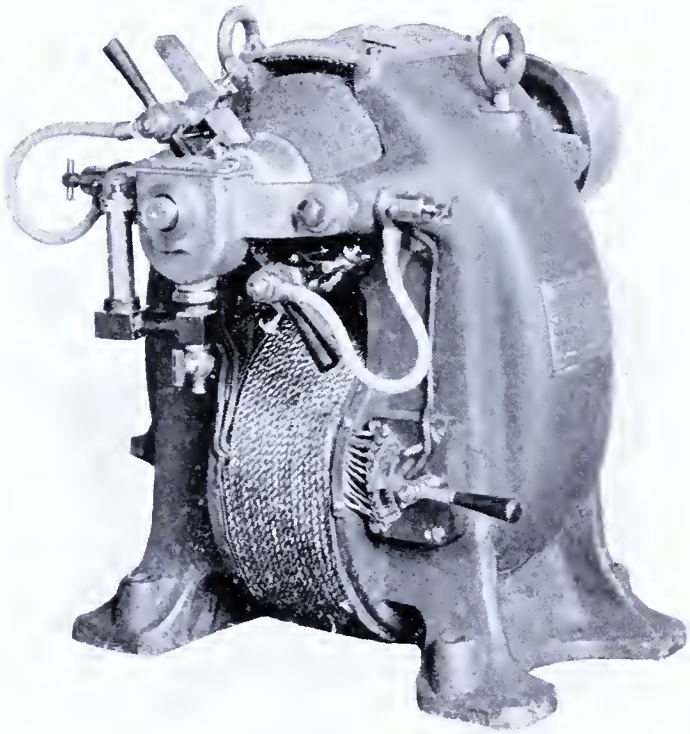
HORIZONTAL TYPE GENERATOR.

Our list of standard sizes of this type comprises the following: —

HORIZONTAL TYPE MACHINES.

Number.	CAPACITY. Generator. 125 Volts. Amperes.	CAPACITY. Generator. 250, 500 Volts. Watts.	CAPACITY. Motor. 110, 220, 500 Volts. Horse Power.	SPEED. Approximate No. of Revolutions per Minute. Generator. 125 Volts.	SPEED. Generator. 250, 500 Volts.	SPEED. Motor. 110 Volts.	SPEED. Motor. 220, 500 Volts.	WEIGHT (lbs.) Gross.	WEIGHT (lbs.) Net.
9	125	15625	20	875	850	840	840	4200	3900
13	200	25000	30	800	775	760	760	5900	5200
17	250	31250	40	575	550	525	525	8400	7500
20	300	37500	50	610	550	500	500	10000	9100
24	375	46875	60	550	525	500	500	11250	10150
31	475	60000	80	485	485	450	450	14000	12800

We also build a line of generators and motors, of capacities not exceeding 15 h.p., of the Letter Type, illustrated in the photograph on opposite page.

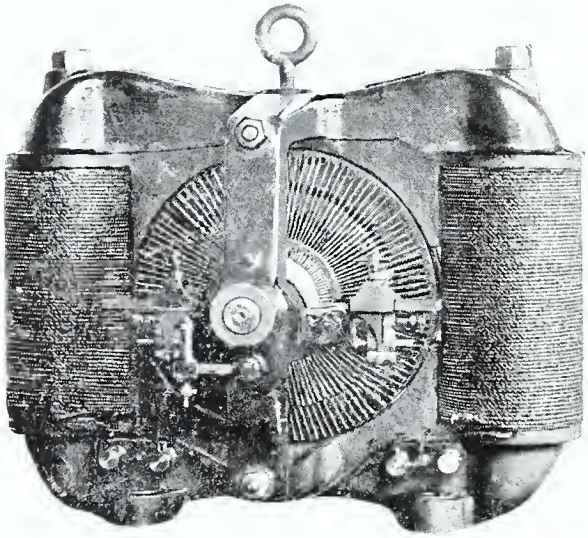


LETTER TYPE GENERATOR.

Our list of standard generators and motors of this type is as follows:—

LETTER TYPE MACHINES.

Number.	CAPACITY.			SPEED.				WEIGHTS (lbs.)	
	Generator.		Motor.	Approximate No. of Revolutions per Minute.					
	125 Volt.	250, 500 Volts.	110, 220, 500 Volts.	Generator.		Motor.		Gross.	Net.
	Amperes.	Watts.	Horse Power.	110 Volts.	250, 500 Volts	110 Volts.	250, 500 Volts.		
B			1/8	1600		1600		57	39 1/2
C			1/4	2000		2000		92	67
D			1/2	1850		1850		168	137
E	9	1125	1	1900	1900	1900	1900	360	300
F	15	1875	2 1/2	1900	1900	1900	1900	550	470
G	30	3750	5	1850	1850	1850	1850	1100	1000
H	45	5625	7 1/2	1400	1400	1400	1400	1950	1780
X	60	7500	10	1300	1300	1300	1300	2180	2000
I	90	11250	15	1300	1300	1300	1300	3190	2990



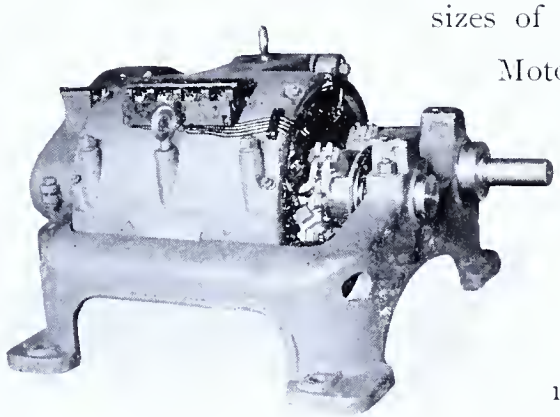
8 H. P. Manchester Motor.

For use in connection with electric cranes, and for other kinds of work in which low speed and very strong starting torque are specially needful, we frequently employ motors of the so-called Manchester type, and we are now prepared to furnish generators of the same general construction. These machines are remarkably compact. They have few parts; are magnetically and mechanically symmetrical; and among bi-polar generators and motors are unexcelled. Our list of standard sizes comprises the following:—

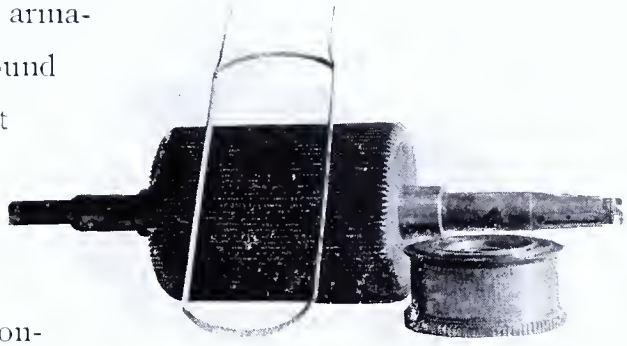
MANCHESTER TYPE CRANE MOTORS.

Horse Power.	Approximate Speed at Full Load.	Approximate. Speed at Quarter Load.	Starting Torque, in Foot pounds.	Length of Shaft.	Height over Fields.	Width over Fields.
2	885	1335	300	30⅝	17⅞	25¼
4	600	900	560	32⅜	19⅞	26½
6	600	1200	870	36	21¼	27½
8	530	830	1000	35¾	24	28¾
12	450	750	2100	41 1/16	23	35
15	400	650	4600	45⅛	28⅛	39¼
20	350	600	7100	64¾	30¼	42

As previously stated, the multipolar machines described in the list on page 31 can, with slight changes, be used as motors as can also the direct current machines of the horizontal type described and illustrated on page 32. In addition to these and to the other types which have been described we have several sizes of our Ironclad Street Railway Motors, which may be readily adapted to almost any kind of work for which electric motors can be used. These ironclad motors have four poles, and are particularly noteworthy for their mechanical strength, high efficiency, very moderate speed, low cost of maintenance, and ability to operate under the most severe conditions. Like the multipolar generators and motors described in the foregoing, they are electrically, magnetically and mechanically balanced. The field and armature coils are machine wound and in case of accident are readily replaceable.



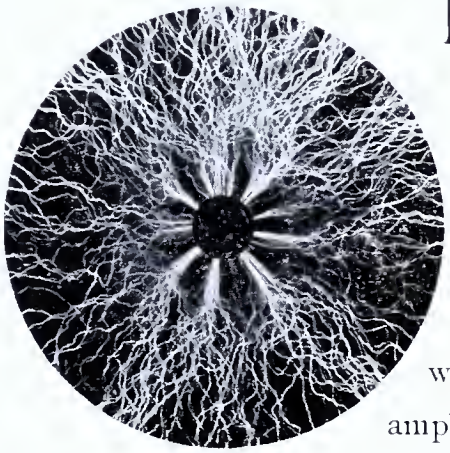
The first of the accompanying illustrations shows one of our Ironclad Railway Motors of the single reduction type, mounted upon a special base. We have designed the motor in this form for use under the extremely difficult conditions prevailing in iron and steel mills. A number of these motors are now in use in prominent mills, where



they are employed to operate cranes, rolls, and transfer tables.

The construction of the armature of this motor is shown in the second photograph, which illustrates the iron core, the commutator, and one of the coils used in winding the armature. The core is of laminated steel; the commutator is built up of segments of tempered copper insulated by mica; the coils are separately wound on spools held in lathe centres, and are insulated by fibre, insulating varnish and rubber tape before they are applied to the core. During the construction of the armature every part is thoroughly tested, and upon completion it is subjected to the strain of a potential several times as great as the armature will be called upon to withstand in practical operation.

Development of High Potential Alternating Systems.



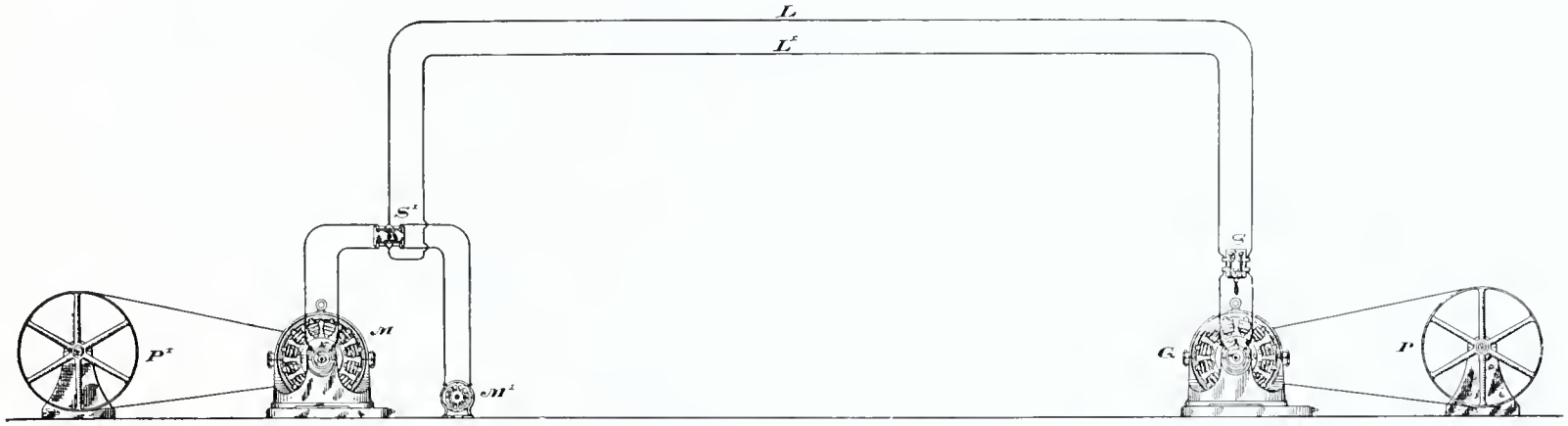
THE WESTINGHOUSE Electric and Manufacturing Company is recognized as the exponent and advocate of high potential systems where conditions make such systems superior in point of efficiency and general utility, and where it is practicable to introduce ample precautions to prevent danger to life and property. The high potential alternating current machinery introduced into this country in 1885, and since then continuously developed and improved by this Company, has been imitated by many competitors. The prestige of being first in the field, the services of many of the most distinguished inventors and designers, and the ownership of a large number of controlling patents, have, from the start, given the Company a commanding position in the field of alternating current work. For the past five years special, thorough and systematic attention has been given to the development of apparatus adapted to long distance transmission of power.

The results of this work are remarkable, and of the utmost practical value. We have developed two distinct systems, namely, the Synchronous, or Two Wire Alternating Current System, and the Tesla Polyphase or Multiphase System. Of these the latter is the more general in its application, and is, indeed, a

universal system adapted to every kind of service. The former is, nevertheless, of great value, and, under certain conditions, and to meet certain requirements, possesses distinct advantages.

In the Two Wire Synchronous System the generator and motor are connected by two wires, and but one current flows between them. In the Polyphase System the generator and motor are connected by three or more wires, and two or more currents, differing in their time relation or phase, traverse the wires. In the Two Wire System the number of alternations which we usually employ is 7200 per minute; in the Multiphase System a lower number is adopted. The Two Wire Synchronous motors are not self-starting. The method of operating them involves the use of a small starting motor of special design, which is used to bring the large motor up to its proper speed before the load is thrown upon the latter by means of a friction clutch, or equivalent mechanism. The multiphase motors start with strong torque, and, consequently, require no auxiliary starting device.

Diagram 3.



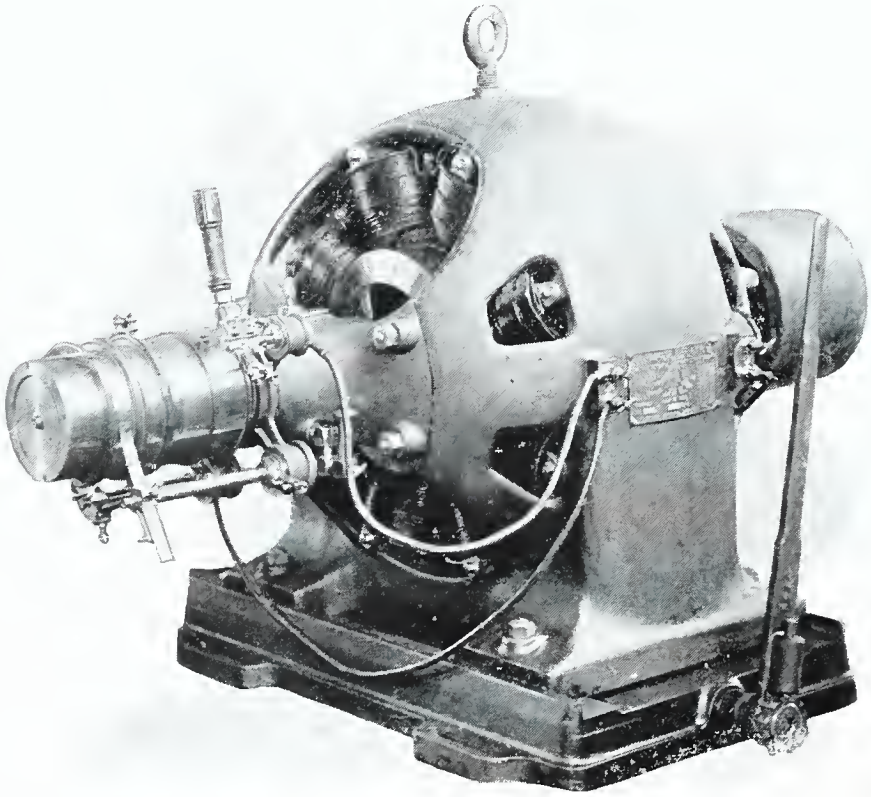
The Two Wire Synchronous System.

THE TWO WIRE Synchronous System in its simplest form is illustrated in diagram 3. The generator, G, is driven by a belt from the pulley, P, which is connected to the shaft of the prime mover, — usually a turbine or water wheel. The switch, S, is used to make or break electrical connection with the line, L, L′. The switch, S′, is used for a similar purpose at the station where the motor, M, belted to the load, P′, is located. It is also used for the purpose of connecting the small starting motor with the circuit at certain times.

The method of operation is as follows: — When the line is charged by the generator, indicating instruments at the motor station notify the attendant that everything is ready. The switch, S′, of the dynamo changing type, is then closed by throwing the handle to the right, so connecting the starting motor and the circuit. This motor, which is a Tesla motor of peculiar construction, rapidly comes up to speed. Arrived at speed, it is used to start the Synchronous motor by means of a friction clutch. In a few seconds the Synchronous motor is at proper speed, this fact being indicated by a special switchboard instrument called the Synchroniser, and the attendant then throws the switch, S′, to the left, so disconnecting the starting motor and connecting the Synchronous motor and the circuit. The starting motor is then

allowed to stop. The whole operation of starting a Synchronous motor, even of the largest size, should not require more than two or three minutes.

This explanation will, perhaps, be made clearer by inspection of the photograph on page 39. This shows one of our 250 h. p. Synchronous motors complete, with starting motor, clutch, and pulley mounted upon the same base or bedplate.

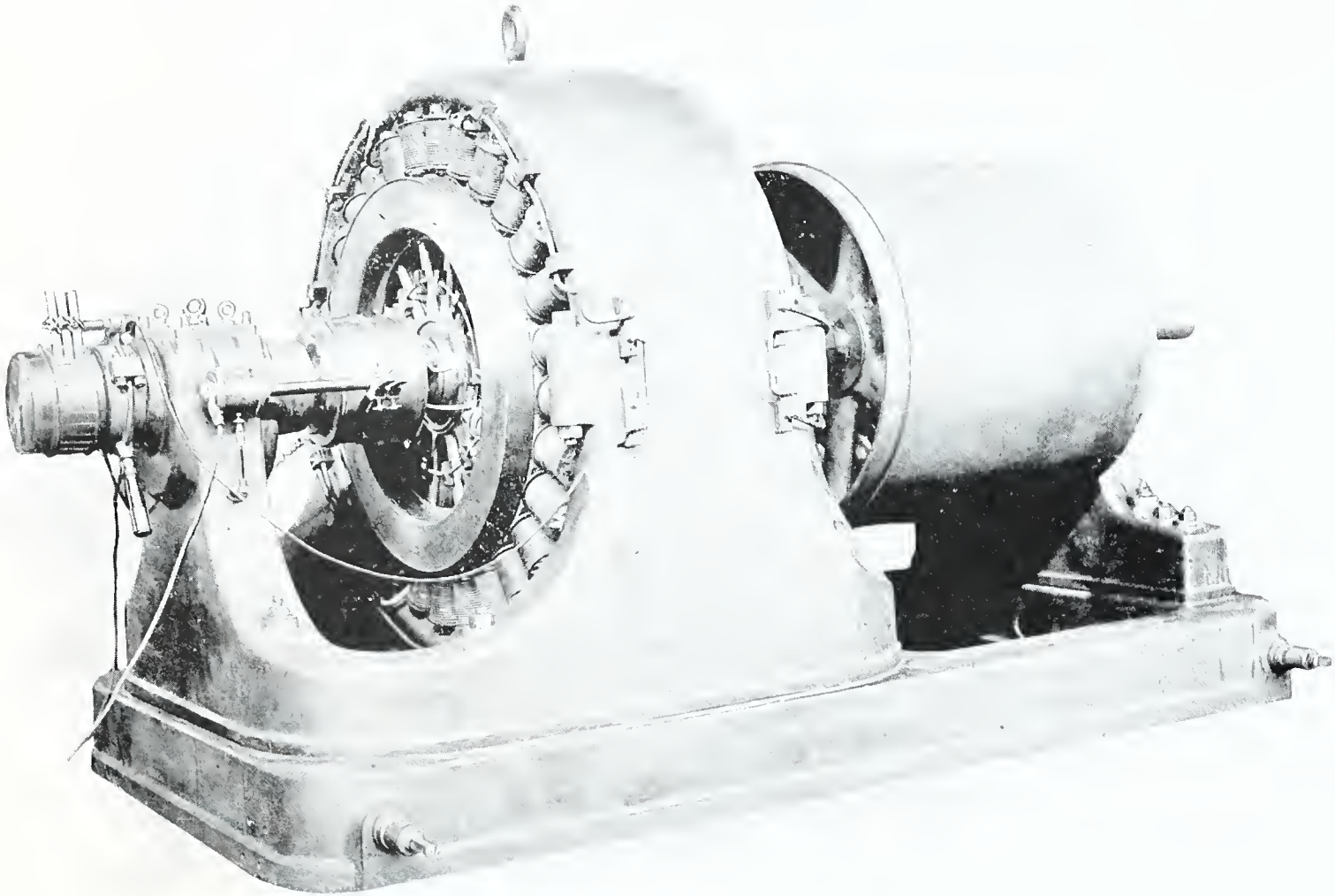


When the starting motor attains full speed its pulley is brought in contact with the narrow pulley on the shaft of the Synchronous motor by means of the screw provided for sliding the starting motor upon its base. The friction of the two pulleys is sufficient

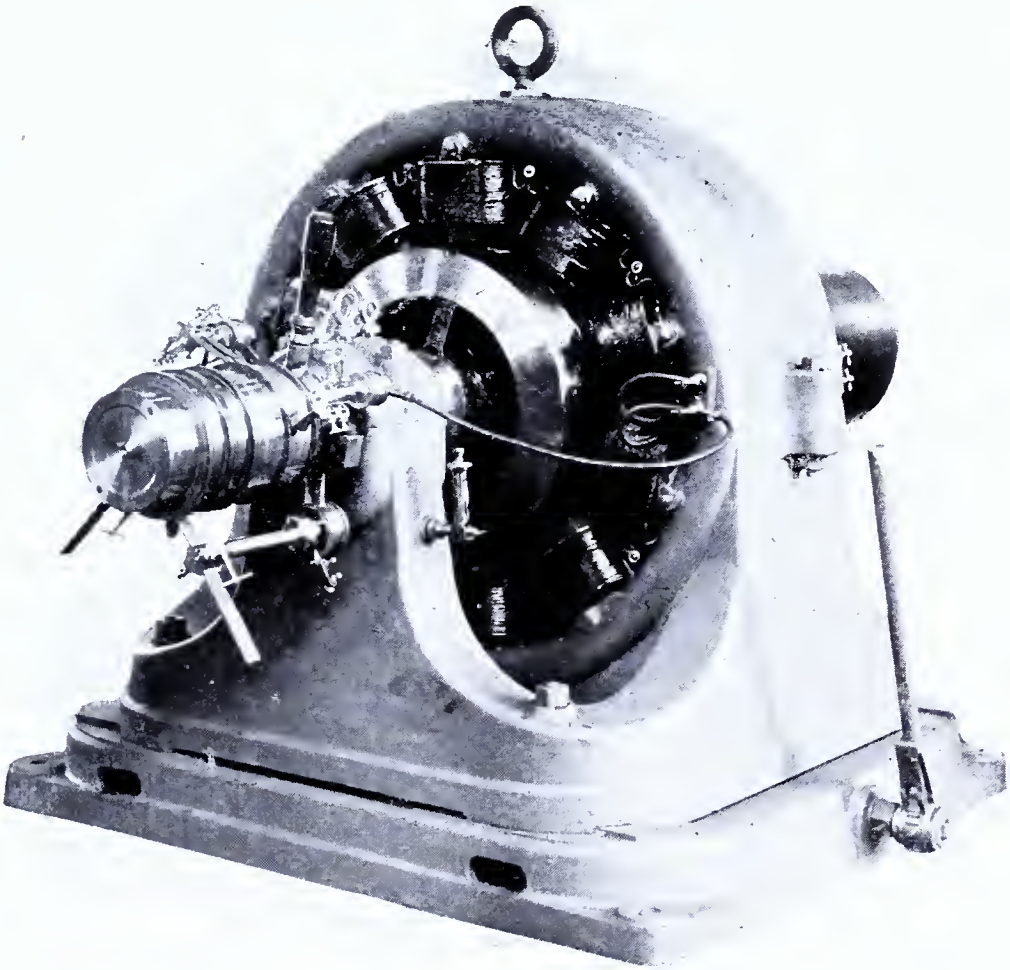
to bring the armature of the Synchronous motor up to full speed. The switch is then thrown; the clutch is gradually tightened by means of a lever provided for that purpose, and the small motor is brought back to its first position, so that the pulleys are no longer in contact.

The photograph opposite illustrates our No. 00 Synchronous Generator. The capacity of this machine is 30 kilowatts. The same machine, with some changes in the winding, is used as a motor.

The photograph upon the following page illustrates our No. 4 Synchronous Generator, capacity 450 kilowatts. The field poles of this machine,—like those of the Multipolar direct current generators,—are built up of thin sheets of steel. The bearings are of the self-oiling type, and an outboard bearing is provided for machines of 250 h. p. capacity and upwards. The photograph shows the machine without the iron rails upon which it is usually mounted, and upon which it may be moved in such a way as to permit adjustment of the belt. Where the speed of the turbine is such as to permit direct connection with the generator a coupling is substituted for the pulley.



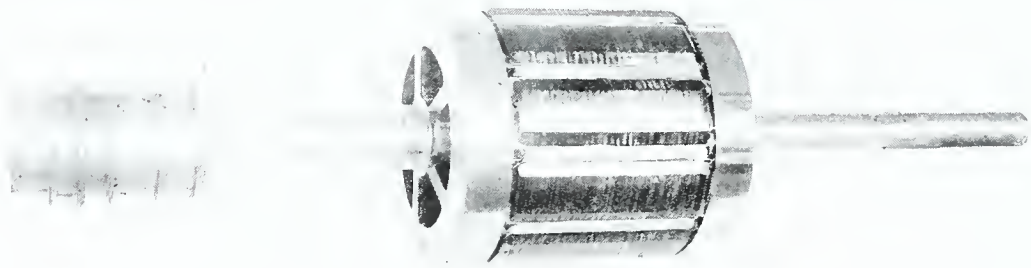
The accompanying photograph illustrates our No. 1 Two Wire Synchronous Motor. The rated capacity is 75 horse power, and, of course, in machines of this size no outboard bearing is required. The field consists of a circular yoke of cast iron having inwardly projecting pole pieces of laminated steel. The coils constituting the field winding are wound upon metal bobbins,



which are slipped over the pole pieces and bolted to the field. There are ten poles, and the standard speed of the motor is 720 revolutions per minute.

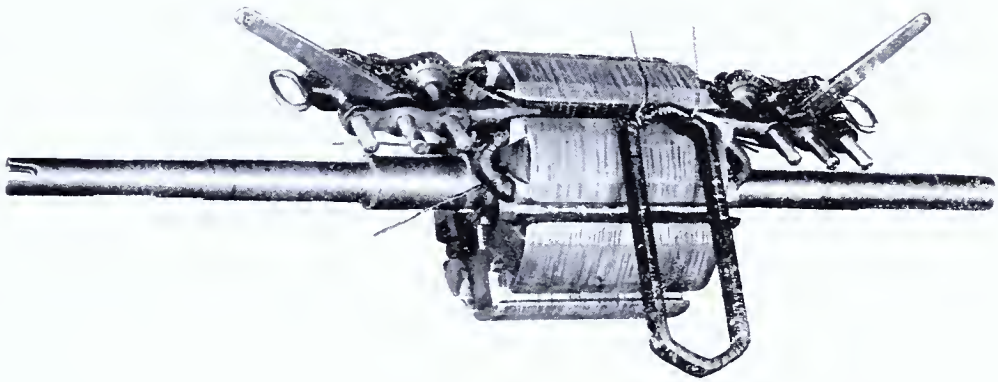
It will be noted that the field is divided, on a horizontal plane passing through the shaft, into two parts. The lower field, and the supports of the bearings are comprised in a single casting. To permit adjustment of the tension of the belt the machine is provided with a sliding base, upon which it may be moved by means of tension screws. The current for exciting the field is obtained from the armature of the motor, and is rectified by a small commutator on the shaft.

The construction of the armatures of both generators and motors will be understood from inspection of the accompanying



photographs, one of which shows the armature complete, while the other illustrates the method of winding. The armature core consists of a large number of thin sheets of special steel having T-shaped teeth. The coils constituting the winding are wound upon moulds or forms held in lathe centres, and are insulated by strips of mica and fibre covered by two layers of rubber tape. The completed coils are slipped over the T-shaped teeth, and are pressed into their proper position by means of a special tool, shown in the photograph. Well seasoned wedges of hard wood are then driven between the coils. No band wires are required, and when

the end plates are in position the coils are entirely protected against mechanical injury. If from any cause the insulation becomes damaged,—as, for example, from a discharge of lightning, —the defect is usually limited to one coil, and this may be readily removed, and replaced by a spare coil.



The standard number of alternations per minute employed in this system is 7,200, but this may be varied, within certain limits, to suit special conditions. Where the generators are driven by water power under high head it will frequently be practicable to couple the shaft of the turbine or wheel to the shaft of the generator, and it may not be easy to obtain standard speed. In such cases it is allowable to operate the machines at higher speeds, corresponding with 8,000, 9,000, or even 10,000 alternations per minute. The minimum speeds at which the generators are capable of delivering their rated capacities are those at which the respective sizes will deliver current at 7,200 alternations per minute. In all cases the number of alternations per minute equals the product obtained by multiplying the number of field poles by the number of revolutions of the armature per minute. The number of poles for each machine of our standard list is shown in the following table, in which the capacity, net and gross weight, and standard speed of the several sizes are also shown:

GENERATORS.

Number.	Exciting Current. Amp.	Exciting Current. Volts.	Capacity in Kilowatts.	Weight in Pounds. Net.	Weight in Pounds. Heaviest Piece.	Weight in Pounds. Gross Weight Boxed for Shipment.	Speed. R. P. M.
00	6	100	30	2470	1125	2860	900
0	10	100	50	3962	1309	4600	900
1	12	100	75	5960	1955	6485	720
2	20	100	150	13200	3360	14000	600
3	35	100	250	23045	5250	24095	450
4	80	100	500	39920	10200	45000	400

MOTORS.

Number.	Capacity. H. P.	Weight in Pounds. Heaviest Piece.	Weight in Pounds. Gross Weight Boxed for Shipment.	Speed. R. P. M.
00	30	1125	3700	900
0	50	1300	5500	900
1	75	1955	8200	720
2	150	3360	18550	600
3	250	5250	31000	450
4	500	10200	51000	360

The starting motors are mounted on the same base as the Synchronous Motors in the case of the larger sizes, namely, Nos. 2, 3 and 4. In Nos. 00, 0, and 1, the starting motors are mounted upon separate bases, and must be connected with the Synchronous Motors by belts. The Synchronous Motors Nos. 00, 0, 1 and 2, are self-exciting, while Nos. 3 and 4 are provided with separate exciters.

All generators and motors of this system are provided with self-oiling bearings. Nos. 2, 3 and 4 have outboard bearings and friction clutches complete, with shifters.

Efficiency.

THE COMMERCIAL efficiency of a generator is the quotient obtained by dividing the electrical energy delivered at its terminals by the energy put into the machine; that is, it is that percentage of the total energy supplied which becomes available as electrical energy.

The commercial efficiency of a motor is that quotient obtained by dividing the mechanical energy delivered at its shaft by the electrical energy which it receives. It is the percentage of the total energy supplied which becomes available as mechanical energy.

The commercial efficiencies of the various machines of the Two Wire Synchronous type are not less than the following:—

Generator.	Efficiency.	Motor.	Efficiency.
00	88%	00	88%
0	88%	0	88%
1	90%	1	90%
2	90%	2	90%
3	92%	3	92%
4	92%	4	92%

In the preceding tables, giving capacity, weight, number of poles, and revolutions per minute, it will be noted that the mechanical output of each motor measured in horse power is exactly equal to the rated electrical output of the generator of corresponding size measured in kilowatts. This allows for a loss of fifteen per cent. in the circuit connecting the two

machines, and for about ten per cent. loss in the motor. The generators are properly rated with reference to their mechanical and electrical factors of safety, while the motors are somewhat underrated as an additional precaution, to prevent the possibility of their being pulled out of step with the generators by a momentary overload. Where the line loss exceeds fifteen per cent. the capacity of the generator in kilowatts is to be taken as the starting point in calculation, and the mechanical output of the motor will, of course, be diminished by an amount proportional to the excess of the actual line loss above fifteen per cent. For example, a No. 2 motor used in connection with a No. 2 generator, and a circuit in which the loss is fifteen per cent. will deliver at its pulley 150 mechanical horse power; but if the line loss be increased to twenty-five per cent. the output of the motor will be decreased to about 135 h. p.

The usual potential at the motor is 3000-volts, but the potential adopted in any given case will depend primarily upon the distance of transmission. Other conditions,—as the efficiency to be obtained, cost of copper, etc.,—will also affect the determination of the potential, and in no instance should potentials unnecessarily high be employed.

The potential at the motors will be kept approximately constant, the generators being provided with a composite winding, the effect of which is to increase the potential at the terminals of the generator by an amount proportional to the load which it carries. This compensation is sufficient to offset the drop or loss of potential in the line. The following are the potentials for which standard motors are designed:—

MOTORS.

No.	Volts.	Volts.	Volts.	Volts.
00	1000	2000	3000	. . .
0	1000	2000	3000	. . .
1	1000	2000	3000	. . .
2	1000	2000	3000	4000
3	1000	2000	3000	4000
4	1000	2000	3000	4000

The potential at generator equals the potential at motor increased by an amount equal to the drop in the circuit connecting the two machines. This drop may be made practically anything desired, but must not be sufficient to call for higher maximum potentials at generators of the respective sizes than those given in the following list:—

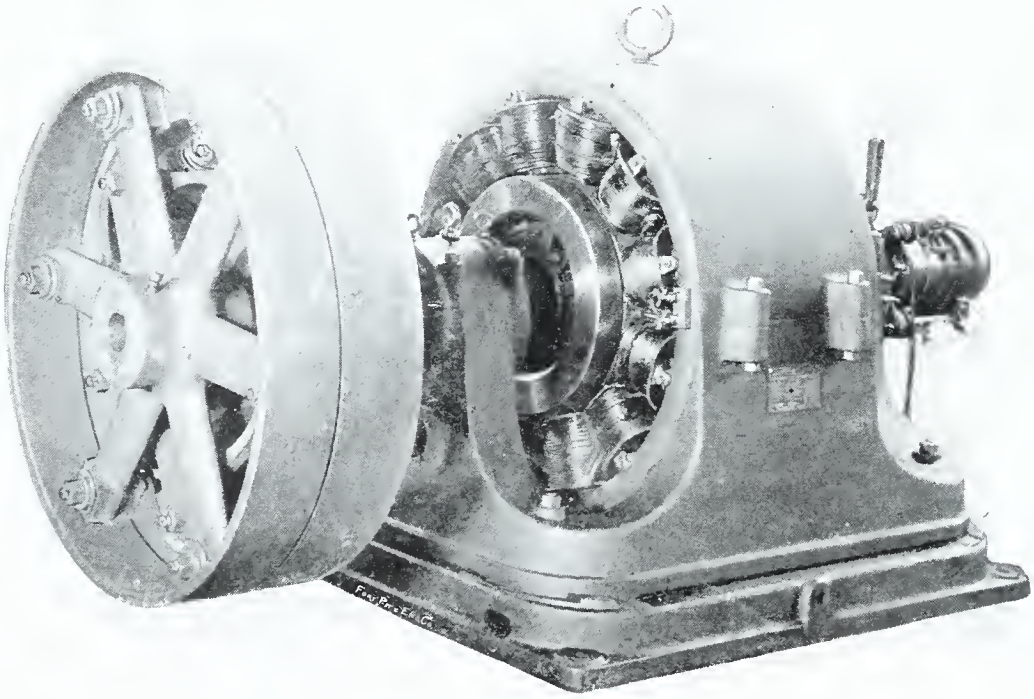
GENERATORS.

No.	Maximum Potential at Terminals.
00	3000 volts.
0	3000 volts.
1	4000 volts.
2	5000 volts.
3	5000 volts.
4	5000 volts.

In any cases where potentials in excess of the above are used it will be necessary to employ raising transformers between the generator and the line; and, in like manner, in all cases where the potential delivered at the motor end of the line exceeds the potential specified for the motor of the size used, as stated in the above list, reducing transformers must be interposed.

Generators used with this system are of two classes, namely, the Direct Connected Type and the Belt Connected Type. In the direct connected generators a special spring

coupling is provided whereby the shaft may be directly connected to the shaft of the turbine, as shown in the illustration. The use of this coupling obviates the necessity of exact alignment of the shafts; that is to say, the centre lines of the shafts need not be exactly co-incident, as would be necessary were a rigid coupling employed.



In the belt connected machines Nos. 00, 0 and 1, are provided with overhung pulleys, while Nos. 2, 3 and 4 have extended bedplates and outboard bearings with pulleys.

General Information.

HERE several generators are employed separate Exciters may be used for each, or one Exciter of sufficient capacity may be used to supply current to the fields of several generators. If practicable, the Exciter should not be driven by the same turbine which is used to drive the generator, since, if it be so driven, a change of speed in the turbine affects the potential delivered by the generator, not only because the speed of the generator is changed, but also because its field charge is altered.

This system is especially adapted to those cases in which no motors of less than 30 h. p. are called for, and in which it is practicable to start the motors without load. There are practical difficulties in the way of commutating the current from a generator of this type, and to obtain direct current for the operation of small motors, or for other purposes, it is necessary to employ a direct current generator driven by a sychronous motor.

The machines may be safely insulated for comparatively high potentials, and therefore the system is applicable to transmission over very considerable distances without the use of raising or reducing transformers. It is a Two Wire system, and the line construction is, consequently, without complication. The number of alternations used is sufficiently high to keep the cost of raising and reducing transformers low, in those cases in which they are

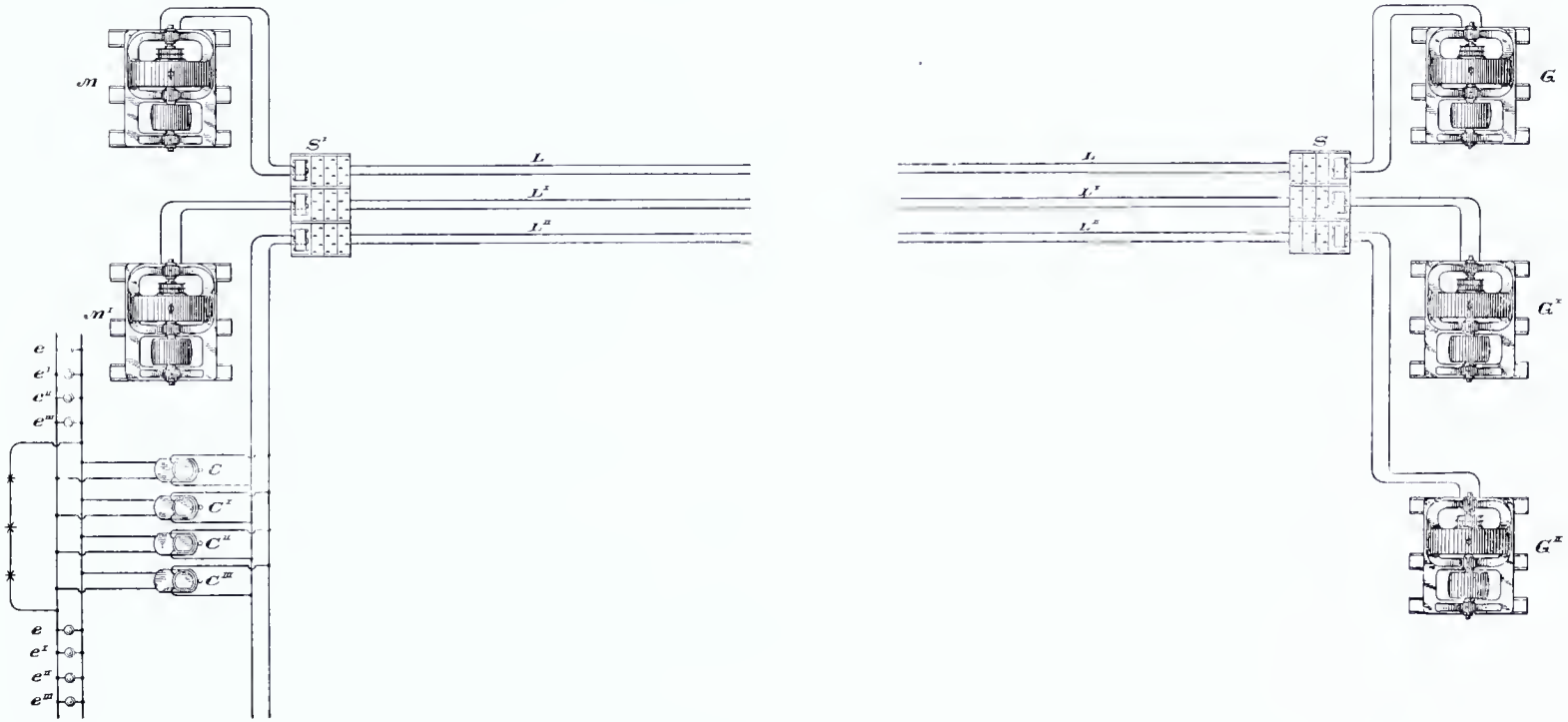
employed, and it also renders practicable the use of the same generators for supplying incandescent lamps, arc lamps and motors.

Where it is desirable to do general lighting in connection with power work it is advisable to erect a substation, conveniently located with reference to the market for power, and to locate therein stepdown converters to reduce the potential to 1,000 or 2,000-volts for local distribution. Standard transformers may then be connected to the circuits, and used to supply incandescent lamps in the ordinary manner. The circuits used to supply incandescent lamps may also supply current to the arc lamps, the latter being connected in groups of two or three lamps, through which the current passes in series.

In Diagram 4, on the opposite page, the application of the system to both lighting and power purposes is illustrated. At the generating station three generators, G, G′, G″, of equal capacity, are installed. By means of the switchboard, S, any of these generators may be electrically connected with any one of the lines, L, L′, L″, which connect the generating station with the switchboard, S′. This switchboard may be located at any point convenient with reference to the motors, M, M′, and the lamps, e, e′, e″, etc., which are supplied from the secondary circuits of the converters, C, C′, C″, C‴, and it provides means for readily connecting motors or lamps to any one of the circuits, L, L′, L″.

The switchboards, S, S′, it will be noted from the above, effect perfect interchangeability of generators, transmission circuits and loads, consisting either of motors or lamps. Any one of the generators may be used to supply lights, or to supply either of the motors. If one or both of the motors are shut down before lamps exceeding the capacity of one generator are needed, the

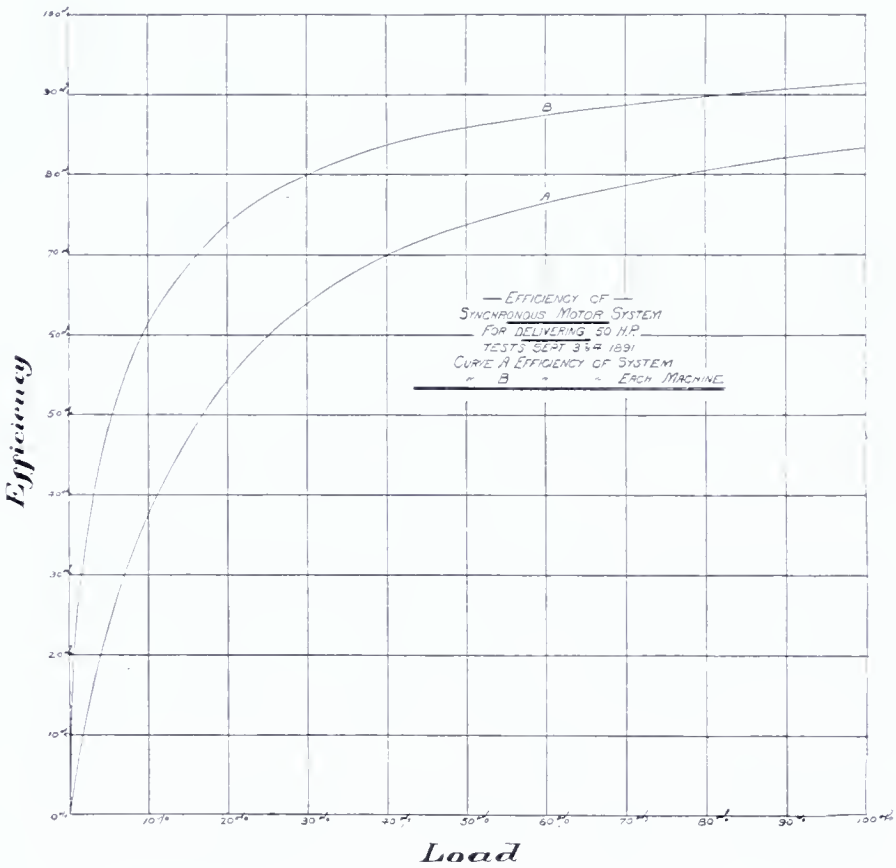
Diagram 4.



aggregate capacity of the motors and lights installed may safely exceed the aggregate capacity of the generating station, and some of the generators may, during the night, be used to supply light.

Where the distance of transmission is such as to make investment in copper excessively heavy at any potential which may be safely used at the machines, raising and reducing transformers must, of course, be employed. They are to be connected between the respective switchboards and the transmission circuit.

THE efficiency of a 50 kilowatt generator of the two-wire synchronous type and of a 50 h. p. motor of the same type is shown graphically in the curves below, which represent results obtained by actual test. The curve marked B shows the ratio of mechanical horse power at the pulley of the motor to the mechanical horse power at the pulley of the generator for various loads. The curve marked A shows the relation



of the electrical energy at terminals of the generator to the mechanical energy at its pulley, and also the ratio of the mechanical energy at the pulley of the motor to the electrical

energy delivered to its terminals. The abscissæ represent the load in percentages of the full rated capacity of the motor; the ordinates represent the corresponding efficiencies. In the tests from which these results were obtained the machines were connected by short and heavy wires, so that there was practically no line loss.

It will be noted that the efficiency of each machine is above 91 per cent. at full load, 89½ per cent. at three-quarter load, 86 per cent. at half load, and 77 per cent. at one-quarter load. In machines of larger size even these very excellent results are improved upon to the extent of from one to three per cent.

The Tesla Polyphase System lends itself to every purpose for which electrical power is used.

It may fairly be called a universal system.

It is equally adapted to supply light or power.

It will supply arc lights and incandescent lamps.

It furnishes power through motors of the rotary field type, or of the polyphase synchronous type.

By means of commutating devices, direct or continuous current is readily obtained for the operation of street railway systems, for electrolytic work, and for all other purposes requiring this kind of current.

By it we may use alternating current for transmission, and may readily obtain either alternating or direct current at practically any potential adapted to any purposes to which electricity is applicable.

Diagram 5.

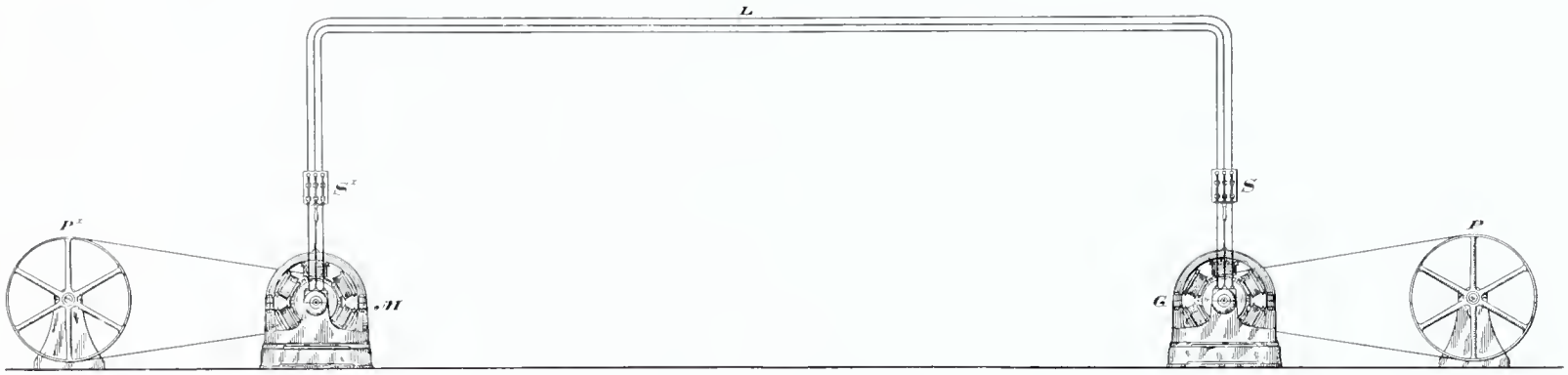


Diagram 6.

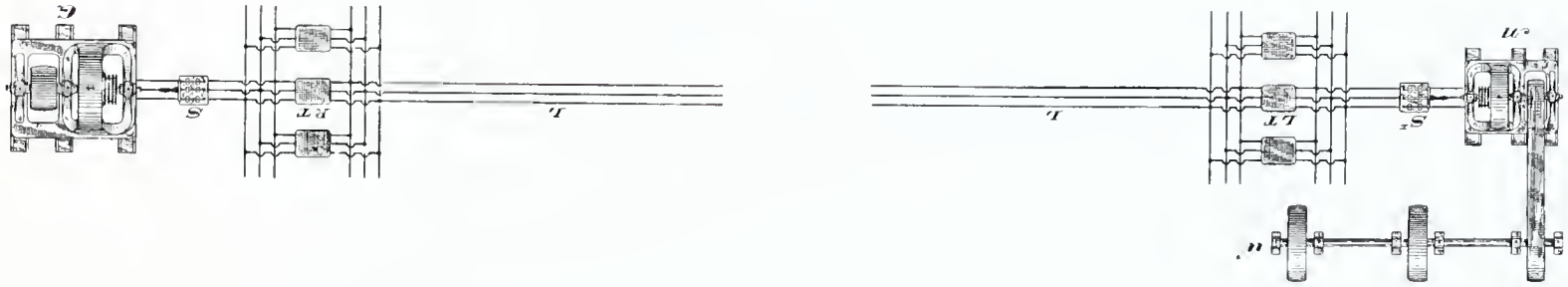


Diagram 5 illustrates the Tesla Polyphase or Multiphase System of transmission, where but one generator and one motor are employed, and are electrically connected by a three-wire circuit of moderate length. The pulley, P, receives power from the prime mover,—ordinarily a turbine,—and is belted to the generator, G. The switch, S, connects the generator and the line, L, and the switch, S′, is used to connect the motor, M, with the line. The motor, by means of a belt, supplies power to the pulley, P′, which is connected with the machinery to be operated.

In Diagram 6 we have the same system, but the distance is assumed to be greater, and raising and reducing transformers are employed. These are shown respectively at RT and LT. The generator is shown at G, and the switch, S, is used to connect the generator to the primary circuits of the raising transformers. The switch, S′, located near the motor, M, is used to connect the latter with the secondary circuits of the reducing transformers. The motor supplies power to the line shaft, W, through a belt.

In each of these diagrams a three-wire transmission circuit is shown. It is always possible to use three wires for the transmission circuit when step-up and step-down transformers are provided, but with some types of multiphase generators and motors the connections from the transformers to the respective machines must be made by four wires. Generally speaking, the four-wire arrangement is preferable for the transmission circuit also, as, with a given limiting potential, this plan requires less weight of copper than the three-wire arrangement.

The universal application of the system is illustrated in diagram 7, on page 63. The generators, A and B, are located at the generating station, and are driven by turbines. Each

generator delivers two distinct alternating currents to raising transformers, RT, RT′, RT″, RT‴, through the switchboard, D. The current, as generated, is of low potential, and may be handled with entire safety, but the raising transformers deliver their currents to the transmission circuits, L, L′, L″, L‴, at a very high potential, e. g., 10,000 volts. At a point conveniently located with reference to the district where lights and motors are to be supplied a substation is erected. The transmission circuits enter the station and deliver their currents to the step-down or reducing transformers, LT, LT′, LT″, LT‴, which, in turn, deliver currents at moderate potentials suitable for local distribution. The switchboard, F, affords means whereby the circuits coming from the various groups of lowering transformers may be readily transferred and interchanged, so that any of the transmission circuits may be used to supply any of the local distributing circuits, as may be advantageous or convenient. In the diagram, beginning at the left of the switchboard, the first four-wire circuit is used to supply alternating current to the motor-generator or rotary transformer, MG, which in turn delivers direct current at 500 volts to a trolley line, from which the street car, K, is supplied. The second circuit supplies the motors, M, M′, M″, M‴, — of the two-phase synchronous type, or of the rotary field type, — which are adapted to general power purposes in mills, factories, etc. The next four-wire circuit is divided into two two-wire circuits, and is used to supply incandescent lamps through the transformers, b, b′, b″. The next circuit supplies alternating current to the motor-generator, MG″, which delivers direct current for arc lighting purposes. The last circuit shown supplies the motor-generator, MG′, which in turn delivers direct current at low potential for electrolytic purposes, as indicated in

DIAGRAM 7.

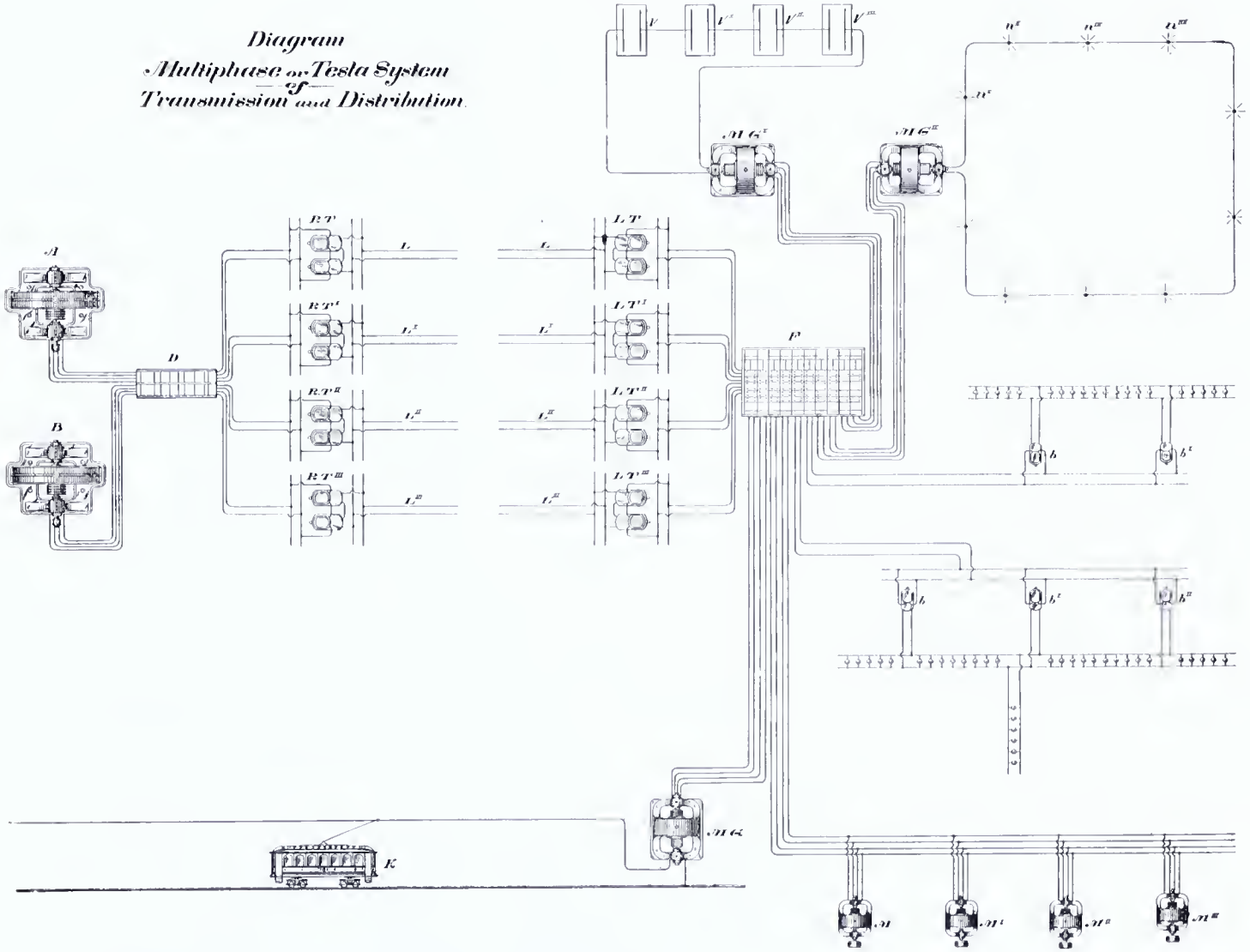


Diagram
Multiphase or Tesla System
of
Transmission and Distribution.

the vats, V, V′, V″, V‴. If the frequency employed be sufficiently high (say 50 periods per second, or 6000 alternations per minute), constant potential alternating current arc lamps may be supplied from the secondary circuits of transformers.

There are several types of two-phase alternating current generators, among which two are especially prominent. Machines of the first type are really double machines, having two fields and two armatures, — the latter mounted on the same shaft. Each armature delivers alternating current to a two-wire circuit, and these circuits taken together constitute the four-wire circuit of the generator, or they may be so connected as to constitute a three-wire circuit.

Machines of the second type have single armatures with two windings, or with a single winding so connected to the ring collectors as to deliver two currents differing in their time relation or phase. Our machines of this type are very similar in appearance to the direct connected generators illustrated on pages 27 and 29. In place of the commutators ring collectors are used, but in other respects the construction is not materially modified.

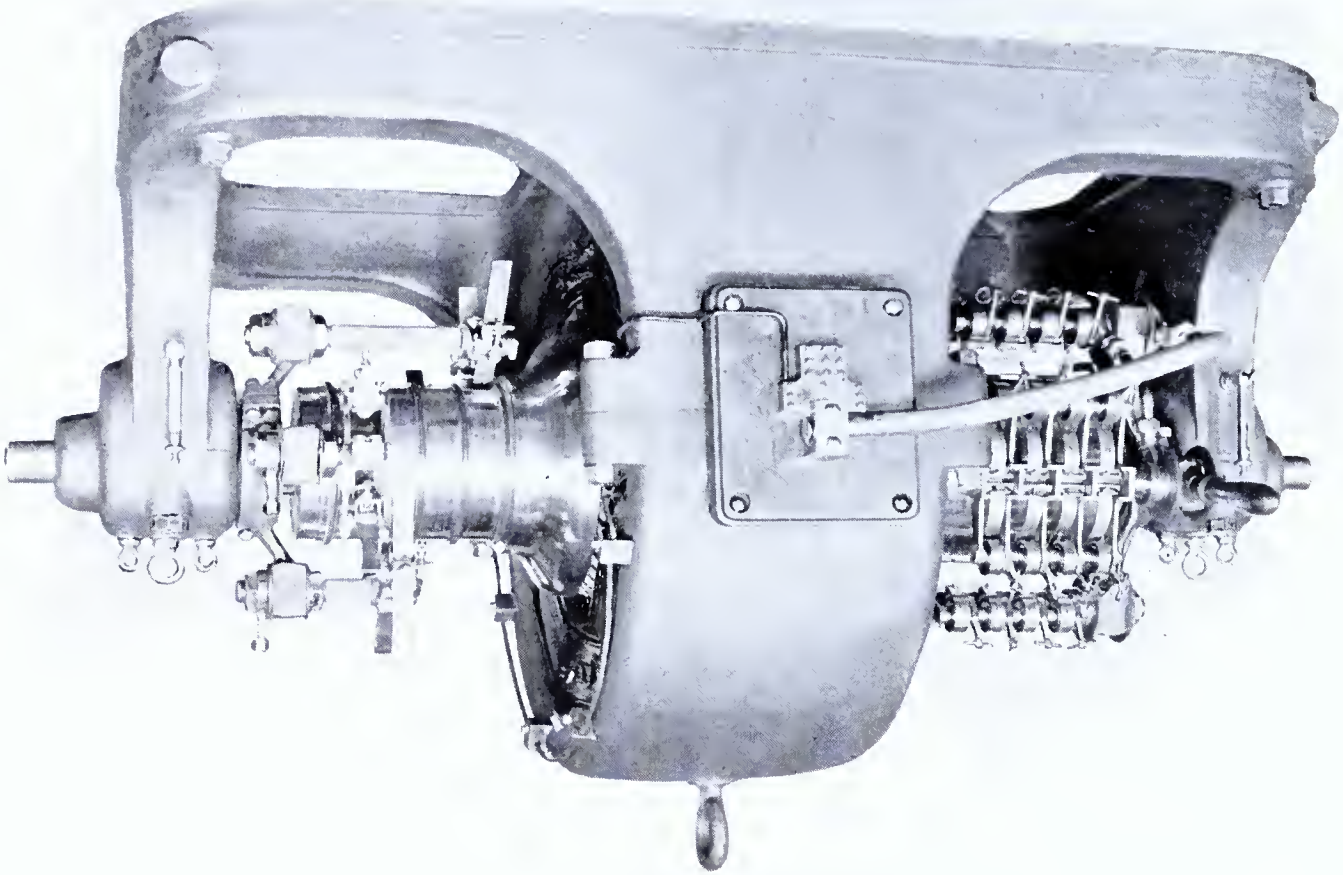
The photograph upon the opposite page illustrates a 1000 H. P. Generator of the first-mentioned class. It is practically a double machine, consisting of two fields mounted upon the same bedplate, and two armatures carried upon the same shaft. As in the two-wire synchronous system the fields are circular castings, having inwardly projecting poles of laminated steel, while the armatures have T-shaped teeth of similar material, beneath which the coils are wedged. A belt-driven generator of this type weighs about 75 tons.

Fairbanks Engl Co.

The Rotary Transformer.

The photograph upon the opposite page shows a Rotary Transformer designed to deliver direct current at a potential of 50 volts. Machines of this type are used for transforming alternating current into direct current at various potentials suitable for the service for which they are employed. The particular machine illustrated is to be used for electrolytic purposes demanding a large quantity of current at low potential, and it will be noted that the brush capacity provided at the commutator end is ample.

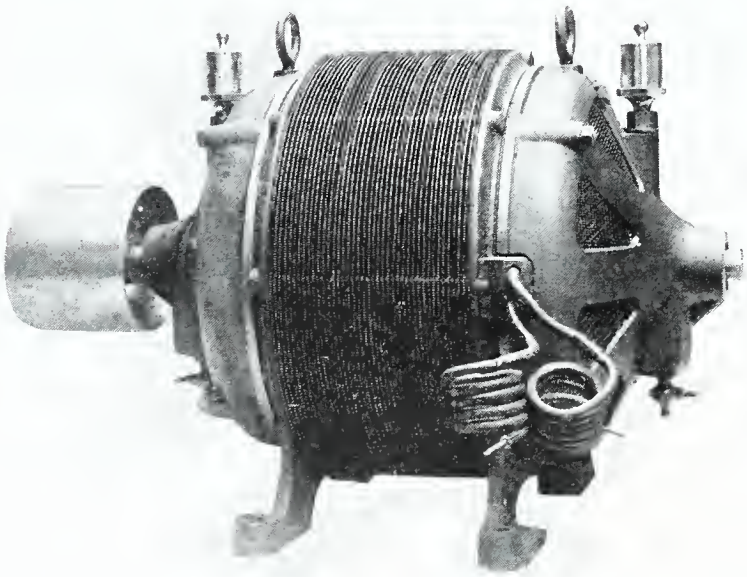
The rotary transformer is, in a general way, constructed on lines similar to those adopted for our multipolar direct current generators; the fields have laminated poles of the best steel, while the armature conductors pass through tubes of insulating material placed in slots about the periphery of the core. The entire framework of the machine comprises but two large castings, — one constituting the lower half of the field and the bearings for the armature, while the other constitutes the upper half of the field.



Tesla Polyphase Motor, 5 H. P.

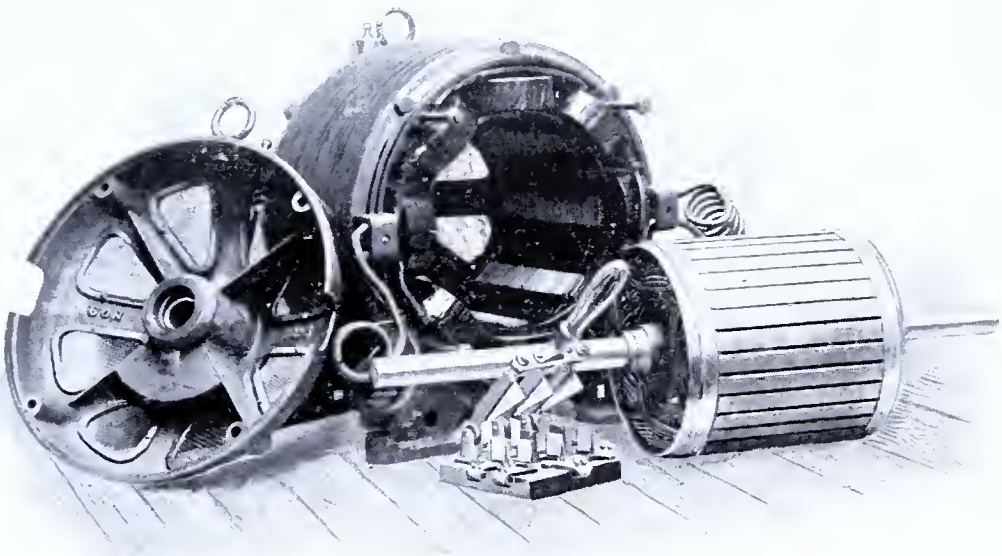
ROTATING FIELD TYPE.

The photograph below illustrates a 5 h. p. Tesla Motor, of the rotary field type, complete, while that upon the opposite page shows the same motor dismantled. It will be noted that the construction is such as to entirely conceal and protect against mechanical injury the coils of both field and armature. Neither commutator nor collector is used. In the Tesla motors



of the two-phase type the winding of the field is made up of two distinct electrical circuits. The currents traversing these circuits differ in their phase; that is to say, the maximum strength of one current occurs at the time when the other current is a minimum, the result being rotation of the magnetism of the field. The armature is short circuited, and the currents traversing it are simply the low potential currents induced by the field.

The insulation of the armature is not at any point subjected to a potential exceeding a very few volts, and it is, therefore, practically impossible to burn out this armature, while the machine may be safely operated in places so exposed to moisture as to make the use of direct current machinery impracticable. The construction of the field admits of very high insulation, and circuits carrying comparatively high potentials may be connected to it without the interposition of step-down transformers.



The starting motors used in connection with our two-wire synchronous system are of this general type, the necessary difference of phase being obtained by special methods of winding the field circuits.

Tesla Polyphase Motor, 500 H. P.

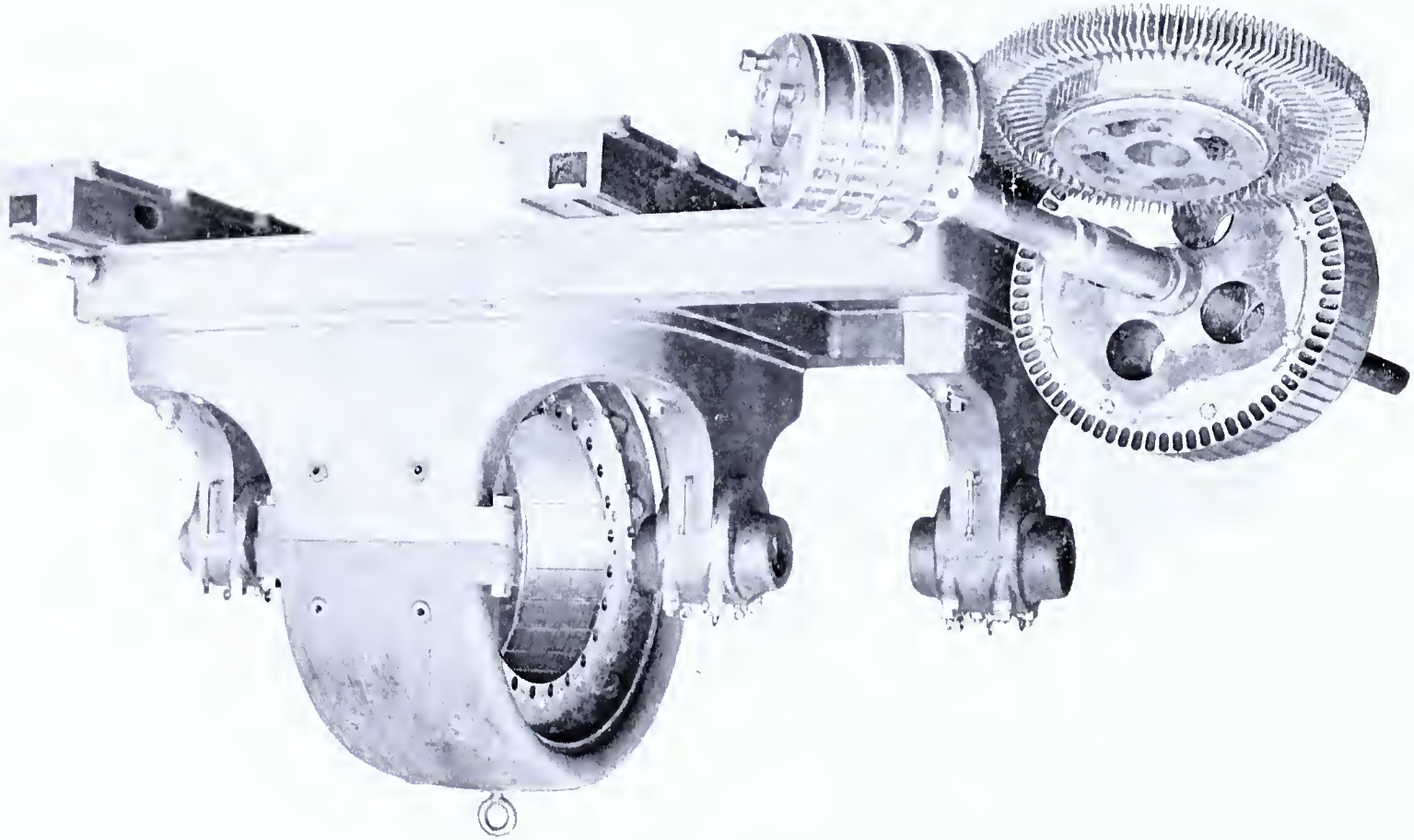
Rotating Field Type.

We illustrate upon the opposite page a 500 H. P. Motor of the Rotating Field Type, dismantled. In this machine the currents are conveyed to the rotating element or armature through the four-ring collector, while the coils of the stationary element or field are short circuited. The photograph was taken before the field and armature were wound. The slots about the outer periphery of the armature and the inner periphery of the field, ready for the reception of the conductors, are plainly shown.

The field consists of a ring of laminated steel set into a cast iron frame, and when in operation only the steel ring is magnetised.

The disc resembling a narrow commutator, and lying near the armature core, is used in making the necessary connections of the armature conductors.

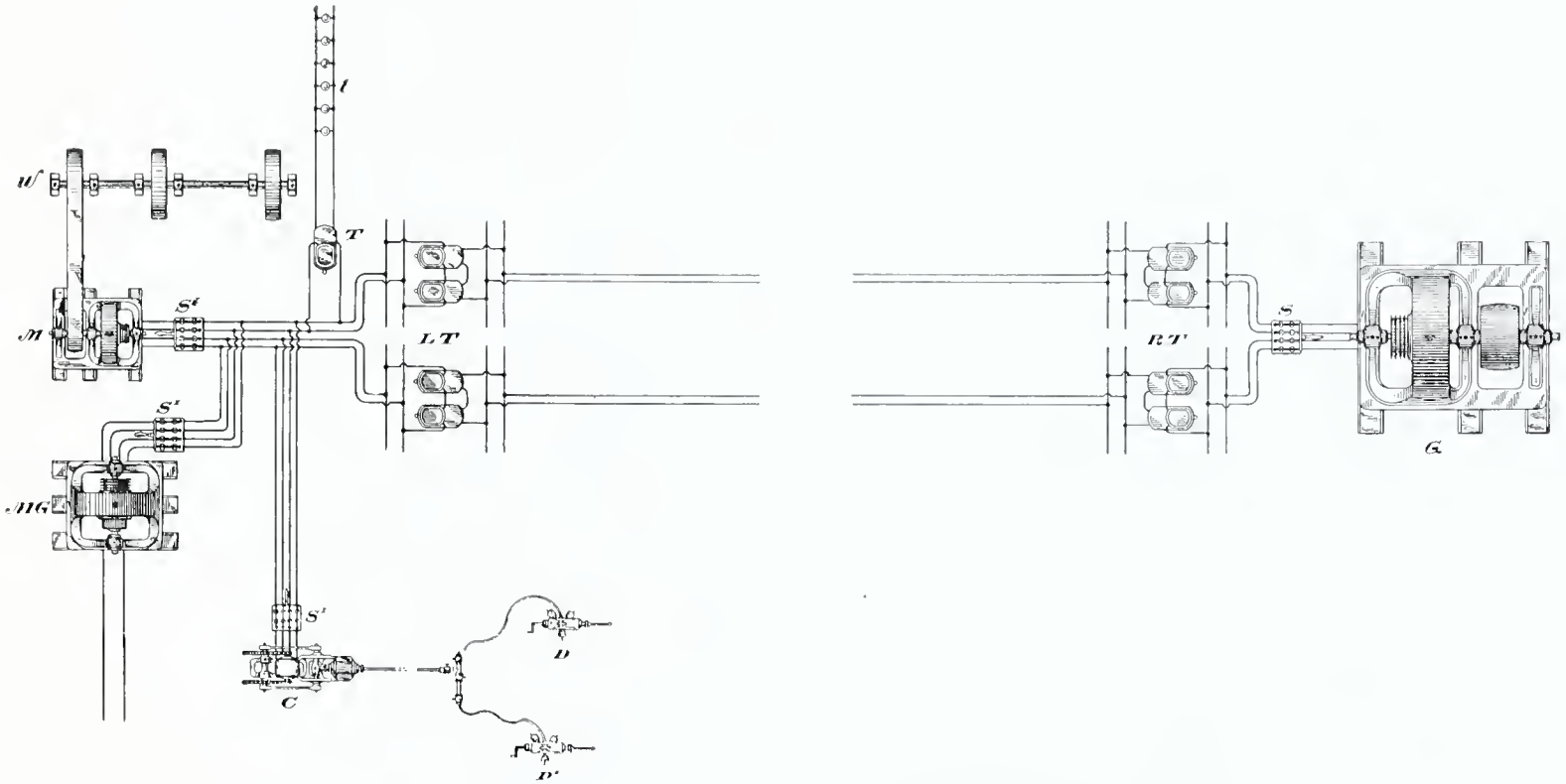
Machines of this type start with strong torque, and regulate well for changes of load.



We illustrate on the opposite page our 60 H. P. Two-Phase Motor of the Synchronous Type. The field of this machine also is of the inwardly projecting radial pole type, while the armature is of the slotted type, requiring no band wires. The four-ring collectors are shown at one end of the shaft, and at the other end the small commutator used to rectify the current which excites the field when the motor is operating in synchronism with the generator will be noted. The machine is provided with sliding base and tension screws for adjusting the tension of the belt. It is fitted with our improved self-oiling bearings.

It should be carefully noted that the great advantages resulting from operating generators and motors in synchronism with each other are not restricted to the machines of the two-wire synchronous system. In the two-wire synchronous system all motors must be operated synchronously. In the Tesla polyphase system, while two types of motors are available, the advantages of absolute speed regulation make it advisable to employ motors of the synchronous type for many kinds of work.

DIAGRAM 8.



Tesla Polyphase Motor,

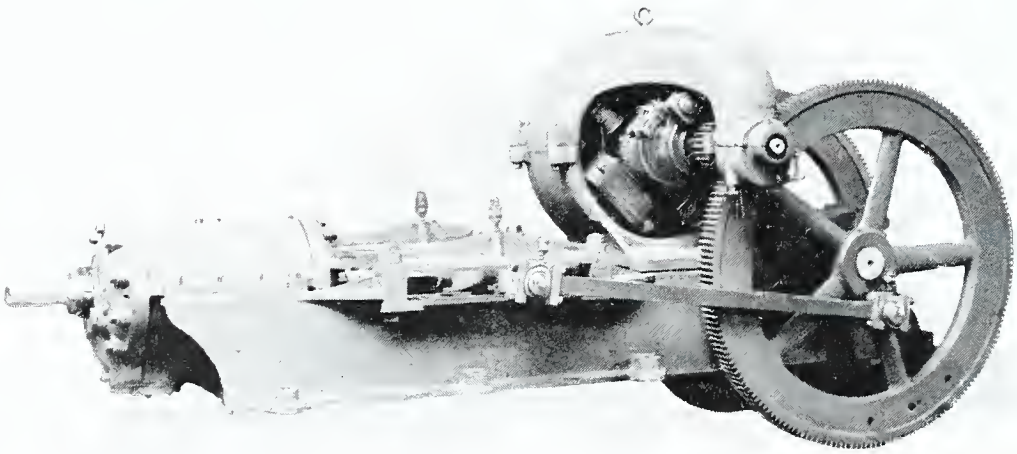
Synchronous Type.

The diagram upon the opposite page illustrates the application of the Tesla polyphase system in a mining country. The generator, G, delivers its currents to the step-up or raising transformers, RT, through the switch, S. At the distant end of the line where the power is to be utilized the step-down or reducing transformers, LT, are located, and from their secondary circuits the various lamps and motors are supplied. Incandescent lamps, l, are connected to the secondary circuits of the transformer, T, it being assumed that in this instance the potential delivered by the step-down transformers is too high for incandescent lamps. The switch, S′, is used to connect the motor-generator or rotary transformer, MG, and the local distributing circuits. This machine, receiving alternating current, delivers from its commutator direct current suitable for the operation of tramways, for electrolytic purposes, etc. The switch, S″, connects to the distributing circuits the motor, M, driving the line shaft, W. A third switch is used in connection with the air compressor, C, which is driven by a motor mounted upon the same bedplate. The motor is of special construction adapted to use in connection with the compressor. As shown in the diagram it is of the multiphase type, but direct current motors are sometimes employed. The drills, shown at D, D′, are standard pneumatic drills.

As is well known the limitations of pneumatic drilling lie in the fact that the cooling of the air in compressor and pipes involves a loss of energy, which, when the distance between compressor and drills is excessive, implies low efficiency. Where

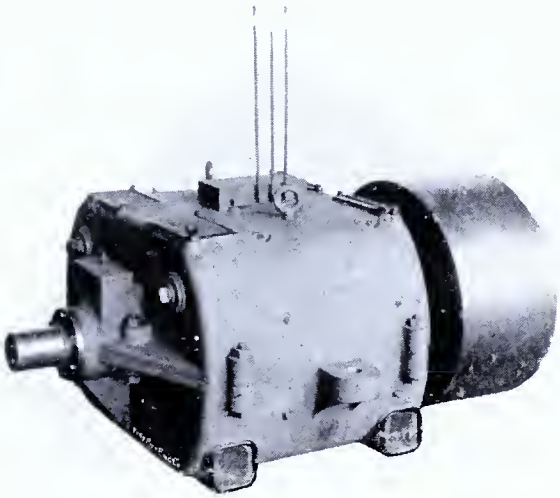
it is practicable to locate the compressor within a moderate distance of the drills a high efficiency is secured. It will be noted that in the arrangement shown in the diagram the compressor, C, may be moved without changing the location of the source of power, it being only necessary to extend the electrical circuit.

This system, while it calls upon mining operators to throw away neither experience nor investment in pneumatic machinery, will, in many cases, enable them to materially increase the efficiency of their pneumatic apparatus; at the same time the introduction of the electrical apparatus provides for other work necessary in mining operations—hauling, pumping, etc.—by a system at once flexible and efficient.



The accompanying photograph illustrates our method of mounting the motor upon a standard compressor originally intended to be operated by steam. The steam cylinder is removed, and the fly wheel ordinarily employed is replaced by large gear wheels.

In this connection we also illustrate a type of motor especially adapted to mining operations. This is our Ironclad Motor, in which, as will be noted upon inspection of the photograph, the armature, commutator, brushes, and field coils are thoroughly protected against dust and moisture.



Advantages of Synchronous Operation.

HEN a motor is operated synchronously its speed depends solely upon that of the generator. No variation in the speed of one can take place without a corresponding change in the speed of the other, and any increase of load upon the motor can, so long as the motor remains synchronised or in step with the generator, reduce its speed only by reducing that of the generator. When motors are operated in this way, therefore, the only element that requires attention in the matter of speed is the prime mover. The electrical apparatus is perfect as regards speed regulation, the speed of the motor being as absolutely dependent on the speed of the generator as if their respective armatures were rigidly coupled to the same shaft.

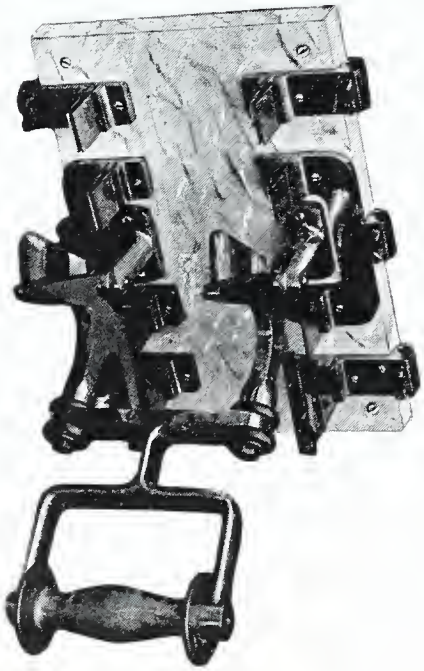
In an electrical system transferring the energy of falling water to mechanical energy available at the shaft of a motor there are three links in the chain of transfer in which variation in speed may appear: first, between the water and the turbine shaft; second, between the turbine shaft and the generator; and, third between the generator and the motor. Excessive variation in the first must be guarded against by proper construction of the hydraulic apparatus, and by the use of effective governors. Where the turbine shaft is connected with the generator by a belt, variation or stretching of the second link can result only from slipping

of the belt, and this can be practically eliminated without difficulty. Where direct connection of turbine and generator by means of a clutch is adopted, there can, of course, be no difference in speed. Unless the synchronous method of operation is employed there is necessarily more or less stretching of the third link; that is to say, the speed of the motor is not exactly equal to that of the generator, and the difference in speed will increase or decrease by a greater or less amount as the load upon the motor is varied. In our two-wire synchronous alternating current system, and in our multiphase system where motors of the synchronous type are employed, this link of the chain is absolutely inflexible.

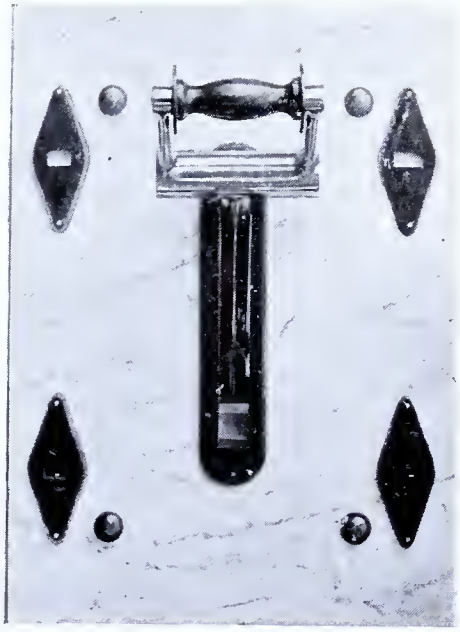
In the two-wire synchronous system, as has been stated, motors are necessarily operated in synchronism with the generators. In the Tesla polyphase system synchronous operation is preferable wherever the nature of the service will permit. For the ordinary work of mills and factories, and for all purposes where constant speed is desirable, while it is not impracticable to bring the motors up to speed without load, motors of this type should be used.

Auxiliary Apparatus and Switchboard Instruments.

IN THE foregoing pages we have illustrated and described a number of generators and motors belonging to our several systems of power transmission, but for the complete equipment of an installation much important apparatus is required in addition to the generators and motors. Unless switches, indicating and measuring instruments, regulating apparatus and safety devices are properly designed and well constructed, excellence of generators and motors will not secure successful operation. A defective switch may render the largest generator inoperative, and a defect in a measuring instrument may result in serious damage to an entire installation. It is, therefore, of the utmost importance that the auxiliary apparatus belonging to a system be worked out and constructed with the greatest care.

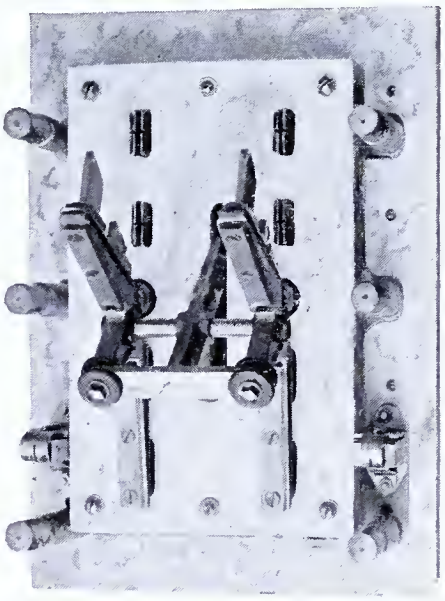


To illustrate all of the devices which we employ in connection with our systems of power transmission would require more space than can be allotted in this publication, and we therefore select only a few of the more important. These, and others not here referred to, are fully described in special circulars, which we will furnish upon application.

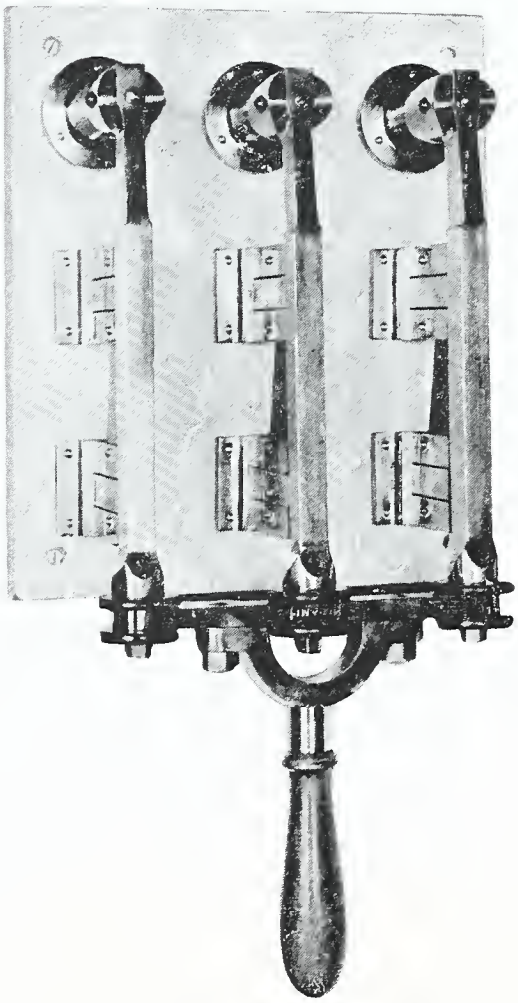


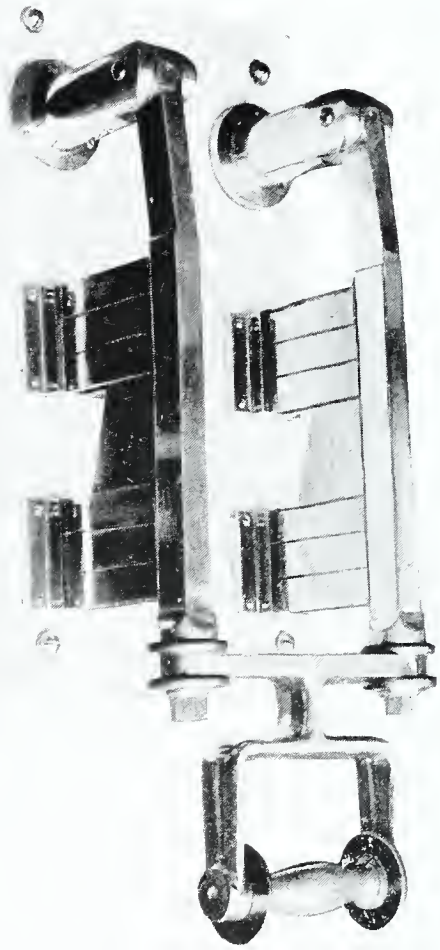
The photograph on page 80 shows a switch extensively used in connection with alternating current machinery. It is called the Dynamo Changing Switch, and is generally used to effect a quick transfer of a circuit from one generator to another.

A switch constructed for similar purposes, but so arranged as to bring all connections, and, indeed, every part that is charged with current, behind the switchboard, is shown in the two photographs on this page. The first is a front view, showing the switch handle projecting to the front of the board; the second is a back view, showing the jaws of the switch, and the terminals to which the respective circuits are connected. Where this type of switch is employed it is impossible for the attendant standing in front of the board to touch any part of the circuits. The construction of these switches is such as to give them great strength. They are mounted upon marble bases.



The accompanying photographs illustrate respectively one of our large Double-Jaw Switches, and a Triple Jaw Switch. The former is used in connection with two-wire circuits carrying heavy currents at moderate potentials.

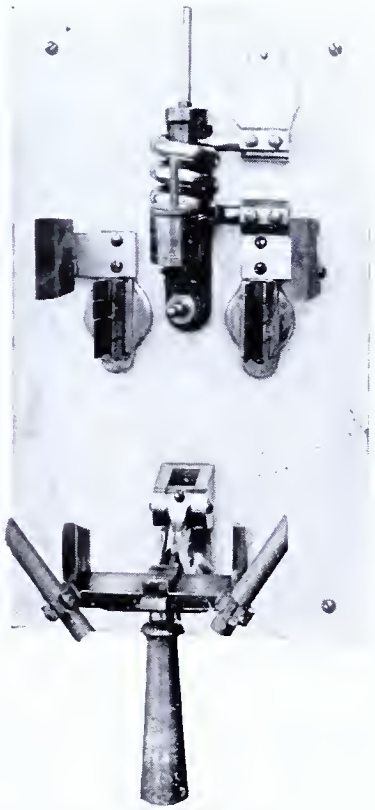


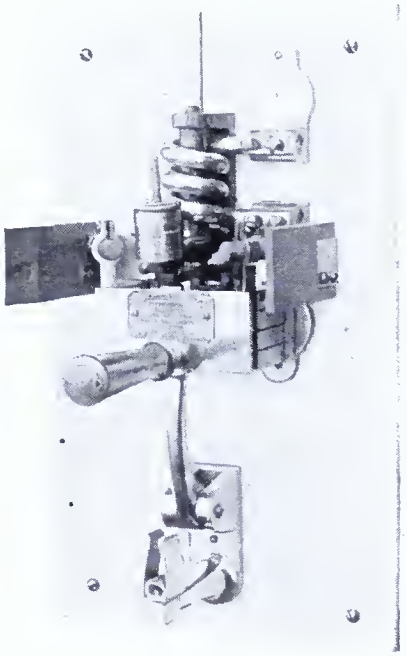


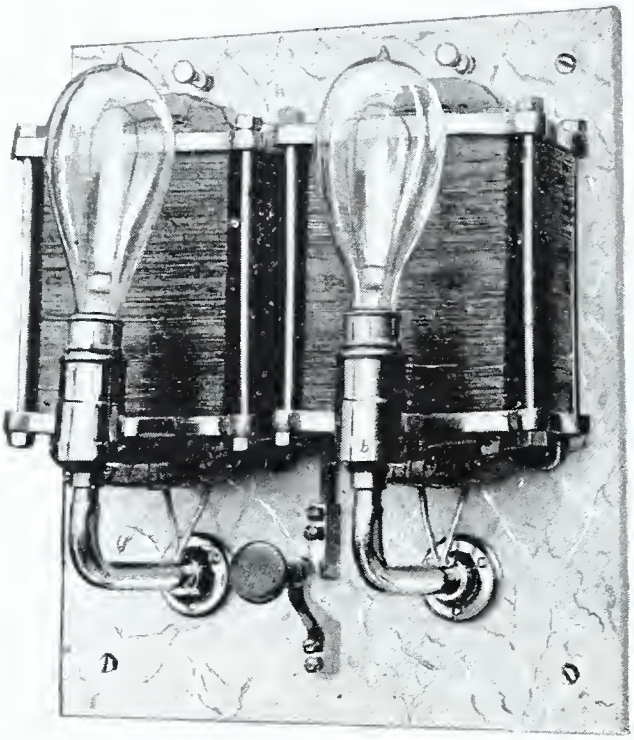
The latter is adapted to three-wire circuits, and is generally employed for connecting direct current generators of the compound field type in multiple arc.

A special safety device, the practical value of which has been demonstrated many times in widely extended service, is the Automatic Circuit Breaker, which is shown open and closed. It consists of an electro-magnet in series with a double break switch. So long as the current passing through the coil of the electro-magnet is not in excess of that which the circuit is intended to carry the circuit breaker remains closed. If, however, for any reason, the current exceeds a certain predetermined limit, the electro-magnet releases a trigger or latch, and the switch is opened by a powerful spring. The circuit is not entirely broken at the moment when the contact terminals attached to the lever arm leave the jaws of the switch, two carbon pencils carried by the lever arm still making contact with carbon plates connected to the jaws of the switch. The final break occurs between the carbon pencils and plates, and the metal jaws of the switch are thus protected.

Adjustment for different currents is secured by changing the weight attached to the armature of the electro-magnet.

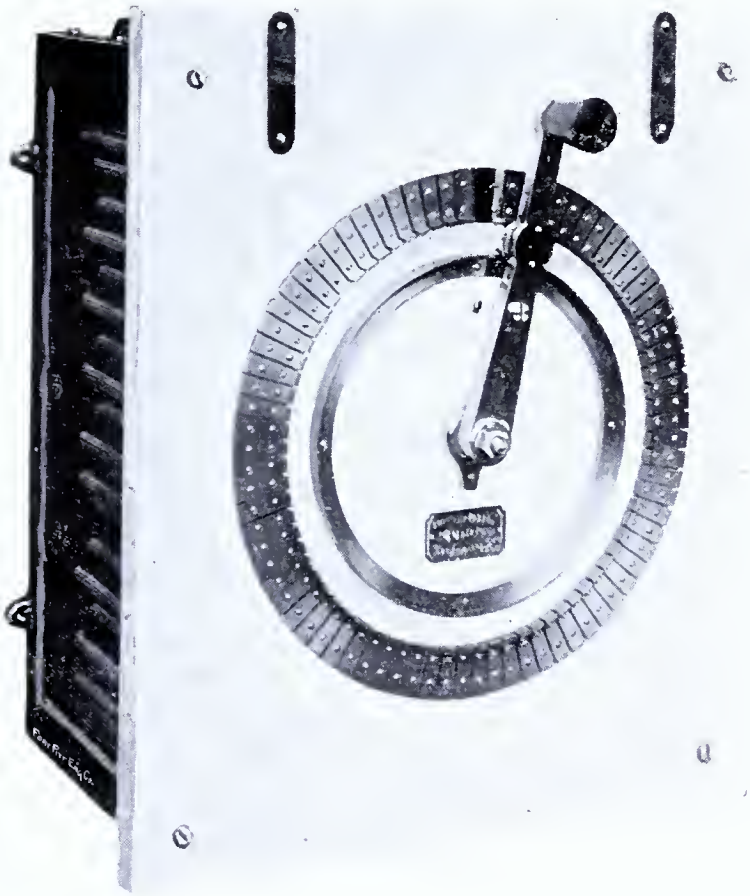




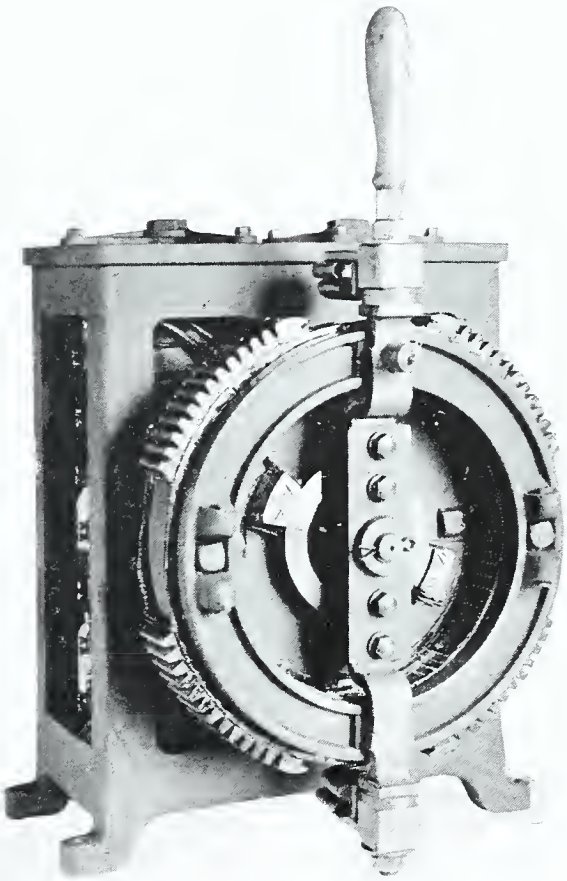


We illustrate herewith our Ground Detector, which is adapted to all alternating current systems. It is a convenient instrument for testing the insulation of circuits, and will instantly indicate a ground. It provides a practical and ready method of applying a test to a circuit while in operation without the necessity of interrupting the service. The materials employed in the construction of this instrument are iron, brass, hard rubber, mica and glass.

We manufacture a full line of rheostats for use in connection with our various lines of generators and motors.



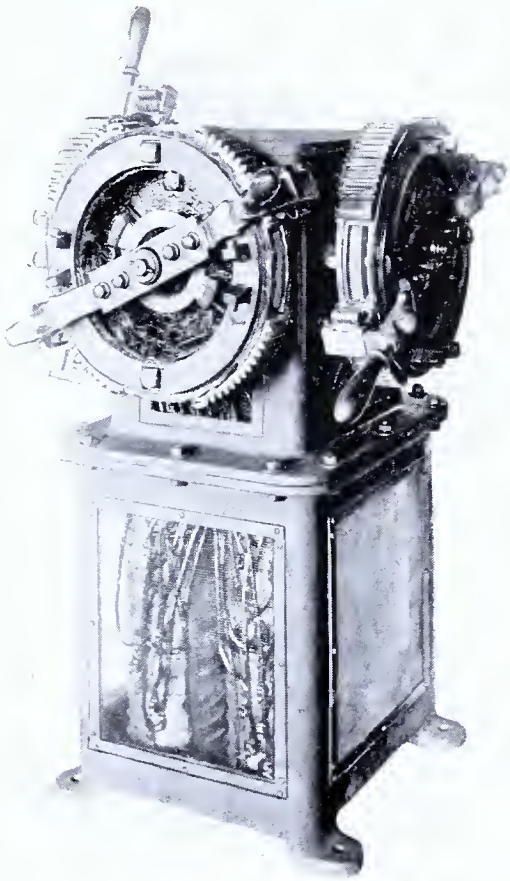
One of our Generator Field Rheostats is illustrated in the accompanying photograph. Noncombustible material is employed throughout. Workmanship and finish are of the highest class.



We manufacture, in addition to the ordinary types of rheostats, a special form, which, for certain kinds of work, possesses marked advantages. This is a combination rheostat and controller with reversing switch.

The accompanying illustration is from a photograph of one of these controllers intended for use with a single motor, while the photograph upon the opposite page shows a combination controller to be used with three motors, and so designed as to enable the attendant to conveniently regulate each of the motors independently of the others.

Noncombustible material is employed throughout, and the construction is such as to insure great strength and reliability.

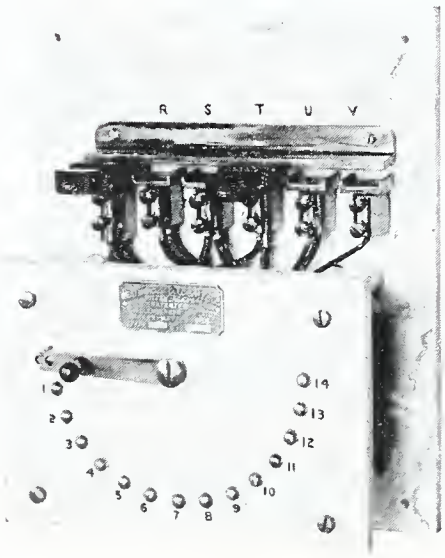


The brushes mounted upon the lever arm make good contact with the terminals of the rheostat. These terminals are built up like the commutator of a direct current machine, and are held firmly in place by a strong iron frame. When the tips become worn they can be readily replaced.

This form of construction is particularly convenient, as it is readily adapted to the combination of any number of controllers not exceeding four in a single frame. Where it is important that the controllers occupy as little space as possible this feature is especially valuable. The type was originally designed for the control of motors operating cranes, but is applicable to many other kinds of work.

The Compensator.

E ILLUSTRATE herewith our Compensator, an instrument which is very extensively used in connection with our alternating current system for incandescent lighting. It consists of a small transformer mounted upon a marble base, and provided with a set of primary terminals and a set of secondary terminals by means of which the active length of either coil may be readily varied. In use these instruments are placed upon the switchboard in the generating station, and are connected to the various supply circuits in such a way that current flowing in each of these circuits traverses the primary coil of a compensator. The secondary coil of each is connected to a volt meter, and when the instrument is properly adjusted the current flowing through this primary coil produces a difference of potential at its secondary terminals which causes a drop in the potential registered by the volt meter corresponding accurately with the drop in the supply circuit due to the resistance of the conductors. The result is that the volt meter at the station indicates a potential corresponding; not with the initial



potential delivered by the generator in the station, but with the potential at the end of the supply circuit where the lamps are located. The function of the compensator is, therefore, precisely that of the pressure wire sometimes employed in direct current installations. When properly set it enables the station attendant to accurately regulate the pressure at the end of a circuit which may be many miles in length, and to do this it is only necessary that he adjust the regulating instruments in such a way as to hold the volt meter index steady. If each supply circuit receives current from an independent generator,—that is, a generator which is not called upon to furnish current to other supply circuits,—the necessary adjustment of pressure is obtained by regulating the field charge of the generator by means of the rheostat provided for that purpose. If, however, several supply circuits are receiving current from the same generator it becomes necessary to provide means for adjusting the pressure of each without disturbing the others. To do this we employ the Stillwell Regulator, which is shown in the accompanying illustration. It consists of a transformer having a secondary coil adjustable in length. Connections are brought out from different points on the secondary coil to a multipoint switch by means of which the secondary coil, or any portion of it, may

at will be thrown in series with the supply circuit. When this is done the electromotive force due to the whole or a part of the secondary coil of the regulator is added to the initial potential of the circuit. The potential of the supply circuit may, therefore, be accurately adjusted independent of whatever may be the potential at the terminals of the generator.

This regulator is extensively used in connection with our central station practice, and its importance in the field of power transmission is obvious. In an installation employing turbines to drive generators, and transmitting power over great distances with considerable percentages of loss in the transmission circuits, it is extremely desirable where this power is used for general purposes, — as illustrated on page 63, — to erect a substation in which are located transformers for reducing potential, and switching devices for the manipulation of the local circuits. The difficulty in obtaining close regulation of the speed of turbines, and the variation in pressure caused by the loss of potential in the long distance circuits, make the use of some such special regulating apparatus at the substation almost imperative.

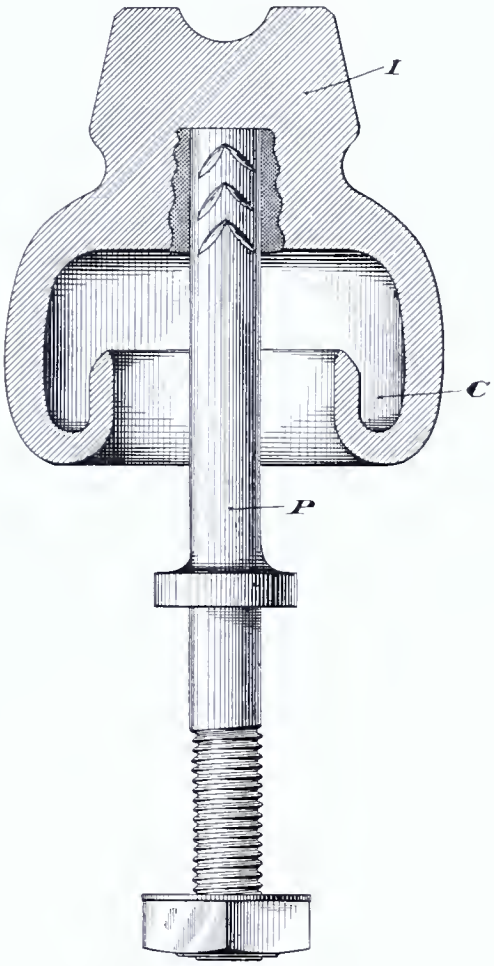
We provide the regulators with reversing switches, the effect of which is to double the range of regulation obtained from a given transfomer by enabling the attendant to reduce the potential in the supply circuit as occasion may require by an amount equal to that which the regulator is capable of adding.

Overhead Lines.

FOR cross-country circuits outside town and city limits we prefer to use bare copper conductors, even when very high potentials are employed. It is unnecessary to use insulated wire, for the insulation of any ordinary line wire will, after exposure to the weather for a time, become ineffectual in affording protection against danger resulting from accidental contact with the circuit. It is obviously advisable, therefore, to avoid the expense of using insulated wires, and to secure safety by adopting every precaution in the mechanical construction of the line. The conductors should be strung upon approved insulators of ample dimensions and substantial design. Poles should be of good size, and should be firmly set in the ground. Where the weight of conductors at a corner, or bend in the line, tends to bring a lateral strain upon the poles, they should be supported and secured by braces or guy wires. Cross arms of sufficient strength to support many times the weight they are expected to carry should be used, and should be very securely fastened to the poles. The length of a span, — that is, the distance between the successive poles, — should never be sufficient to involve danger that the wire may break of its own weight, and in calculating strains upon conductors it is wise to allow very liberal factors of safety. Where a line passes over a highway, or enters the limits of a town or city, every precaution against possible danger by falling wires must be observed. If the construction is still overhead guard wires should be provided.

The highest practicable insulation of an overhead circuit is obtained by the use of fluid or oil insulators, which are so designed that any current leaking from the conductor to the earth or to the other terminal of the circuit must, before reaching the pin, pass over a surface of oil. There are several forms manufactured, some having a single oil cup, while others have more than one. We illustrate herewith a single cup insulator, as made by Johnson & Phillips, London, England. The insulator is of porcelain while an iron pin is used. In America glass insulators are more commonly employed while wooden pins are generally used. The illustration on the opposite page shows a section of the insulator, from which its construction will be readily understood. The insulator, I, is connected with the iron pin, P, the latter being grooved to secure a firm joint. The cup, C, is partially filled with oil when the insulator is in use. No matter how wet the insulator may become the surface of the oil will always interpose an extremely high resistance between the conductor and earth.

It is sometimes inconvenient to employ oil insulators, and we have, therefore, designed a special insulator without oil, which we have successfully employed in transmitting energy at 10,000 volts potential over a distance of twenty-eight miles. The top of a pole with cross arms equipped with insulators of this type is shown on page 9. The plant where this is accomplished is now in operation, and is a success from a commercial as well as an engineering standpoint. At the time when the installation of this plant was completed, by connecting a twenty-eight mile circuit in series with a fifty-six mile circuit we obtained a circuit eighty-four miles in length, corresponding with a single distance of forty-two miles. The bare copper conductor was supported upon over 3,200 of these insulators. The potential employed was slightly in excess of 10,000 volts. Under these conditions energy amounting to over 130 h. p. was successfully transmitted, and careful measurements were made at both ends of the line. The results obtained verified the theoretical calculations in a most gratifying manner.



Mechanical Features of Westinghouse Apparatus.

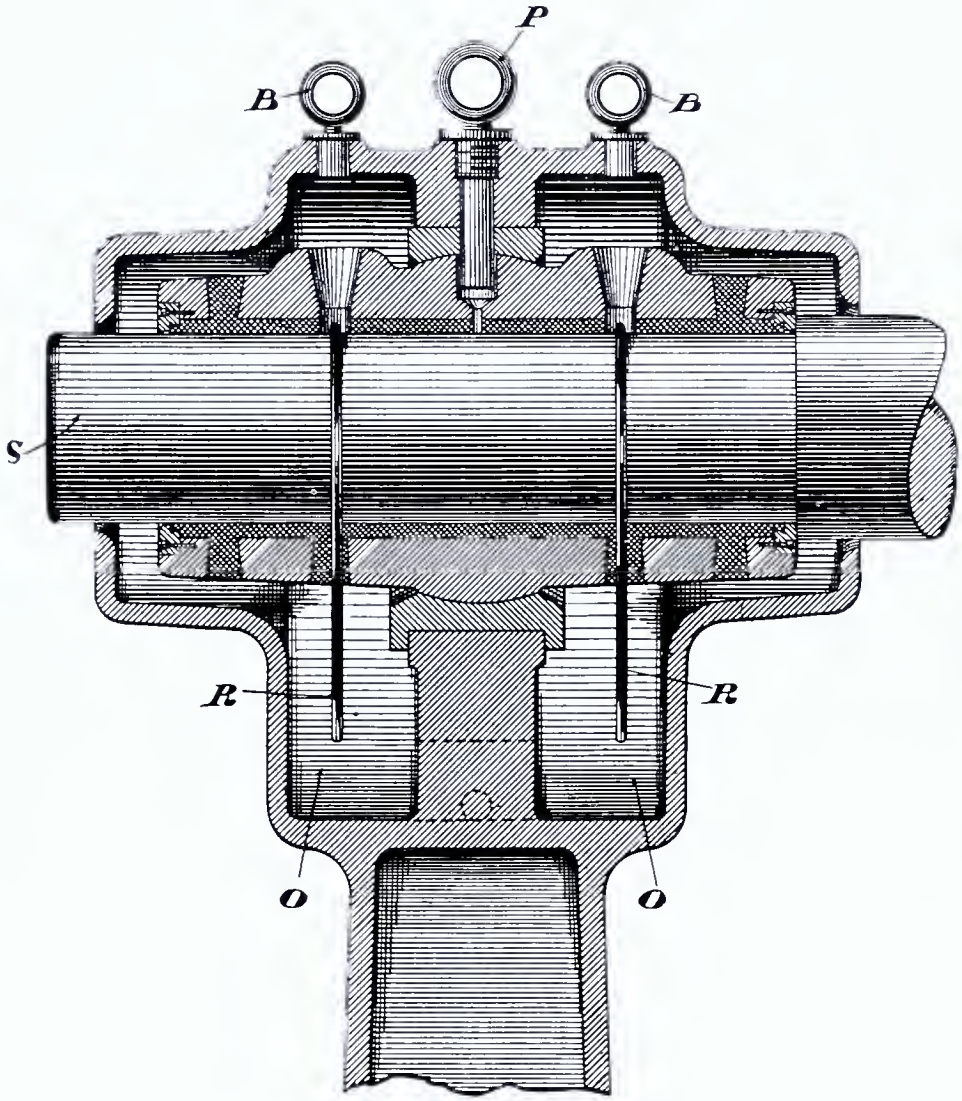
IN GENERATORS and Motors mechanical perfection is no less important than electrical excellence. Our Company has never sacrificed the former to the latter, and we make the claim that while our machinery is at least equal as regards regulation and efficiency to the best machinery offered by competing companies, it is distinctively superior as regards mechanical features.

The apparatus which we offer for the transmission of power represents the results of years of experience and careful study. No expense in experimental research or in practical test has been spared, and our machines embody practically the highest possibilities of dynamo and motor design. Inspection of the illustrations on the preceding pages, — all of which are from photographs, — will show that both generators and motors are symmetrical in form, and that the construction is such as to secure great rigidity of frame. Easy access to every part is provided, and so far as possible the parts are made interchangeable.

In a dynamo or motor we have simply the rotary movement of the armature, there being no reciprocating parts. If, therefore, the armature be perfectly balanced, and the bearings ample, mechanical wearing of parts in this class of machinery is a minimum. Every armature that is turned out of our shops is first accurately balanced upon knife edges, and properly weighted. Shafts are of forged steel, and self-aligning ball bearings are exclusively used.

One of the bearings of a large alternator is herewith illus-

trated. The rings, R, R, which rest upon the shaft, S, are carried around slowly by friction when the machine is in operation, and lift oil from the reservoirs, O, O, in quantities sufficient to secure thorough lubrication. The reservoirs are filled with oil through



the openings in the top of the bearing, normally closed by plugs, B, B. The pin, P, locks the bearing and the shaft bushing.

In all machines, except a few of the smaller sizes, we employ the multipolar type of field, which consists of a cast iron ring having inwardly projecting poles. These poles are usually of

laminated steel, and are cast into the ring or frame of the machine. The field divides in two parts on a horizontal plane passing through the shaft. Provision is made for readily lifting off the upper half by means of an eye-bolt; when this is done the armature is readily removed. The lower half of the field with the extension of the base and the supports for the bearings constitute a solid casting. This construction secures the greatest possible rigidity of the parts, and is far superior to the ordinary method of bolting the bearing supports to the base.

In the preceding pages we have several times referred to the fact that excellent results may be obtained from alternating current arc lamps if the frequency selected for the system be suitable. A great deal depends upon the quality of the carbon used. With a high class cored carbon, and a frequency of from forty-five to sixty, — that is, from 5,400 to 7,200 alternations per minute, — an excellent light is obtained, while the arc is almost noiseless.

We have several types of lamps, some of which are adapted to out of door use, while others are intended for indoor lighting. An ornamental lamp adapted to alternating current circuits, and suitable for the lighting of stores, hotel offices, etc., is shown in the accompanying illustration.